

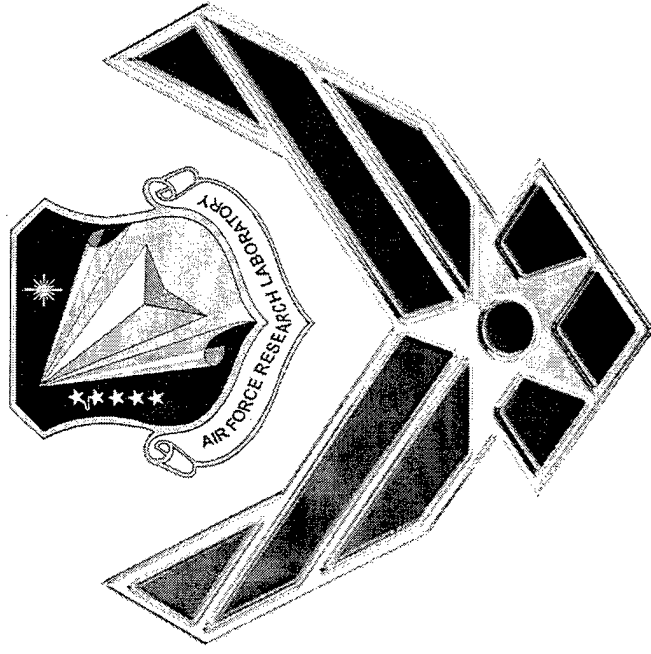
REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY) 19-10-2003		2. REPORT TYPE Technical Viewgraphs		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Design, Synthesis, and Characterization of New Ionic Liquids				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Greg Drake, Tommy Hawkins (AFRL/PRSP); Kerri Tollison, Greg Kaplan (ERC); Jerry Boatz, Leslie Hall, Ashwani Vij, Jeff Mills (AFRL/PRSP)				5d. PROJECT NUMBER 1011	
				5e. TASK NUMBER 0046	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048				8. PERFORMING ORGANIZATION REPORT NUMBER AFRL-PR-ED-VG-2003-234	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S NUMBER(S) AFRL-PR-ED-VG-2003-234	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES For presentation to University of Alabama and NASA/Marshall (general public audience).					
14. ABSTRACT					
<div>20031119 031</div>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	A	43	Leilani Richardson
					19b. TELEPHONE NUMBER (include area code) (661) 275-5015

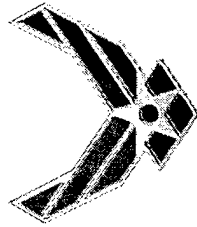
DMC copy 10/31

Design, Synthesis and Characterization of **New Ionic Liquids**



Greg Drake and Tom Hawkins
AFRL/PRSP
Air Force Research Laboratory
Edwards AFB, CA 93524

Distribution Statement A: Public Release material, unrestricted release.



Ionic Liquids



Those involved in this work



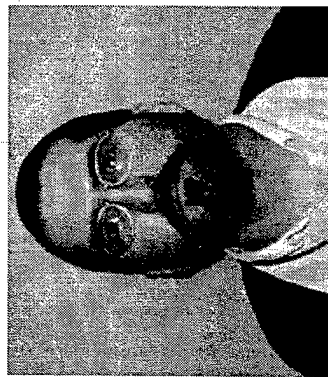
Ms. Kerri Tollison
Synthesis and
Characterization



Greg Kaplan
Synthesis and
Characterization



Jerry Boatz
Theoretical
Calculations



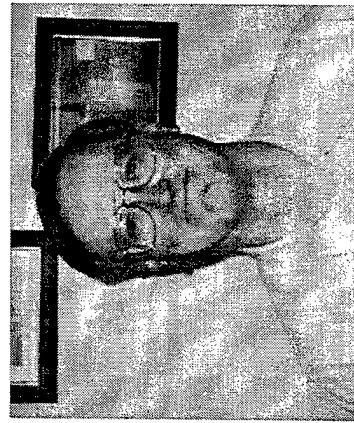
Jeff Mills
Theoretical
Calculations



Leslie Hall
Synthesis &
x-ray work



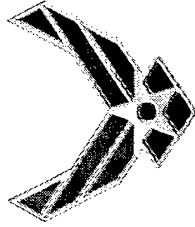
Ashwani Vij
X-ray
crystallography



Tommy Hawkins
6.2 Propellant
Development



Greg Drake
6.1 Research
Synthesis

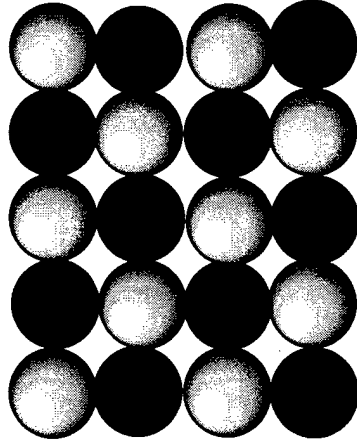


Ionic Liquids



versus

NOT



Extended lattice

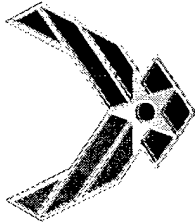
Table salt Na^+Cl^- m.p. = 804 °C Very high
Cryolite Na_3AlF_6 m.p. nearly 1000 °C (Hall Process for Al production)
Eutectic of Li^+Cl^- and K^+Cl^- m.p. 355 °C

Molten salts are very hot!

Not commercially viable

Corrosion and energy issues

Giant lattice of miniature magnets stuck together



Ionic Liquids



What are Ionic Liquids?

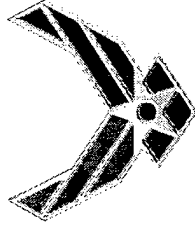
A class of salts consisting of cation/anion pair that has a very low melting point.

Definition of an ionic liquid is open to some debate amongst researchers in the area, but most in the area use one of two.

(1) An ionic compound that melts below 100 °C (b.p. of H₂O). J. Wilkes, P. Wasserscheid, K. Seddon.

(2) An ionic compound that has a melting point at or below ambient temperatures. These are often called RTILs (Room Temperature Ionic Liquids) T. Welton, R. Rogers.

But many of the salts fit both definitions and (2) is really a more specific class of (1).

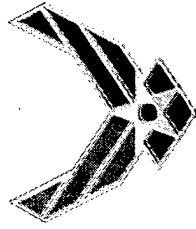


Ionic Liquids

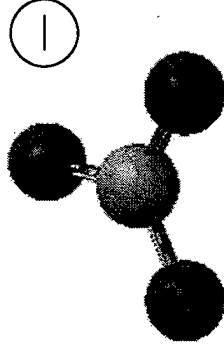
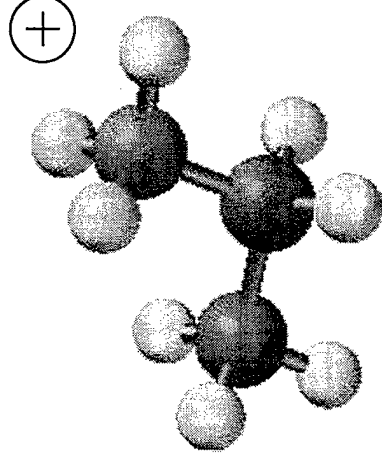
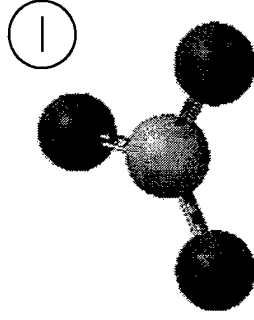
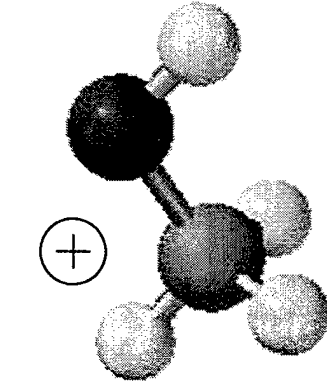
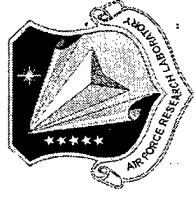


Important factors affecting the physical properties of ionic liquids

1. Asymmetry of cation as well as anion
2. Packing efficiency
3. Charge delocalization in cationic/anionic species
4. “Sheer size” differentials



Ionic Liquids



Hydroxylammonium nitrate (HAN)

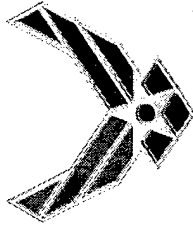
$[\text{NH}_3\text{OH}^+][\text{NO}_3^-]$ m.p. 39-40 °C

Ethylammonium nitrate

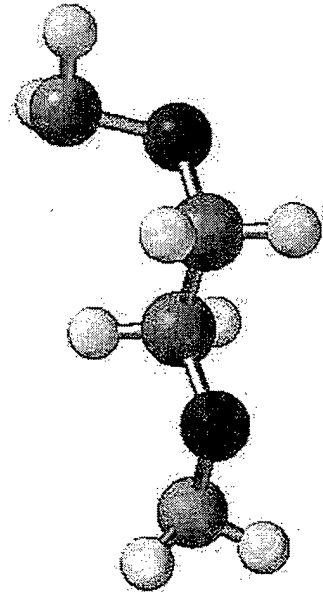
$[\text{CH}_3\text{CH}_2\text{NH}_3^+][\text{NO}_3^-]$ m.p. 12 °C

Serious issues...

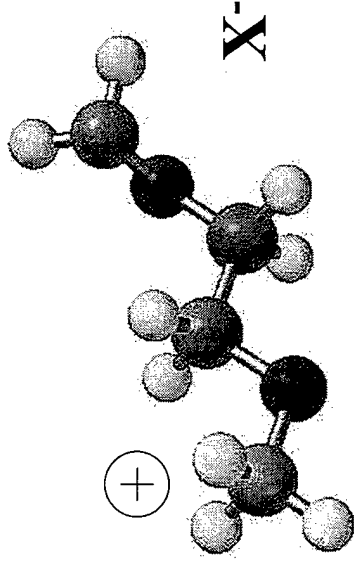
- can be treacherous
- acidic
- very hygroscopic



Ionic Liquids



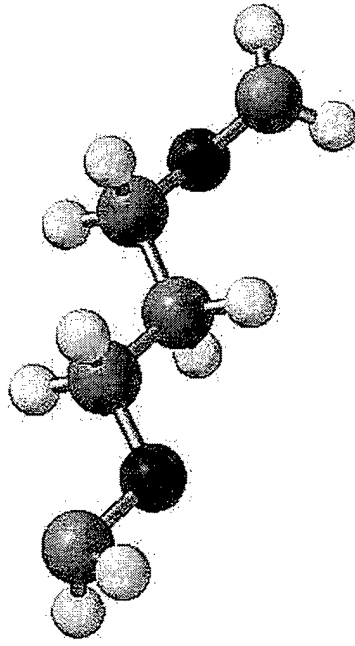
H-X



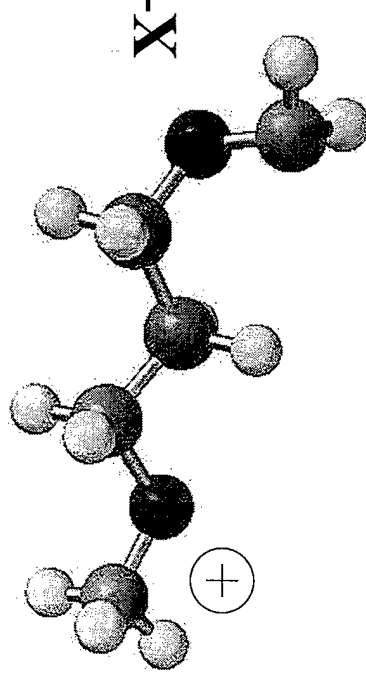
1,2-bis(oxyamine)ethane

Dixon, D. W.; Weiss, R. H. *J. Org. Chem.* 1984, 49, 4487

1,2-bis(oxyamine)ethane mono salts
 $X^- = NO_3^-$, ClO_4^- , $C(NO_2)_3^-$, $N(NO_2)_2^-$



H-X

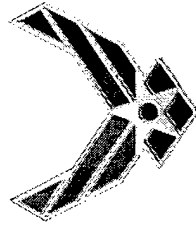


1,3-bis(oxyamine)propane very stable, watery liquid

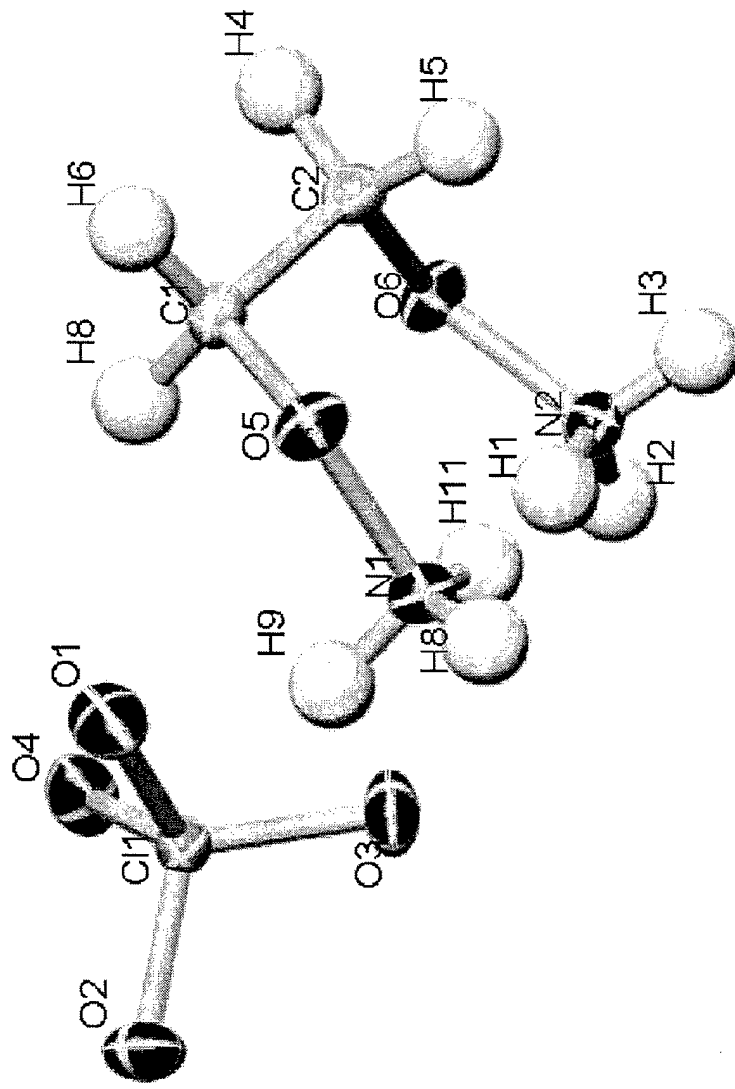
b.p. = 65-70 C @ 0.3 torr; f.p. = glasses at -40 C

1,3-bis(oxyamine)propane mono salts
 $X^- = NO_3^-$, ClO_4^- , $C(NO_2)_3^-$, $N(NO_2)_2^-$

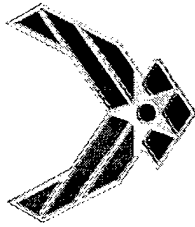
Bisoxamines are stable as neutrals but protonated versions are not (extremely friction and impact sensitive!) Direct contrast with simple mono oxamines.



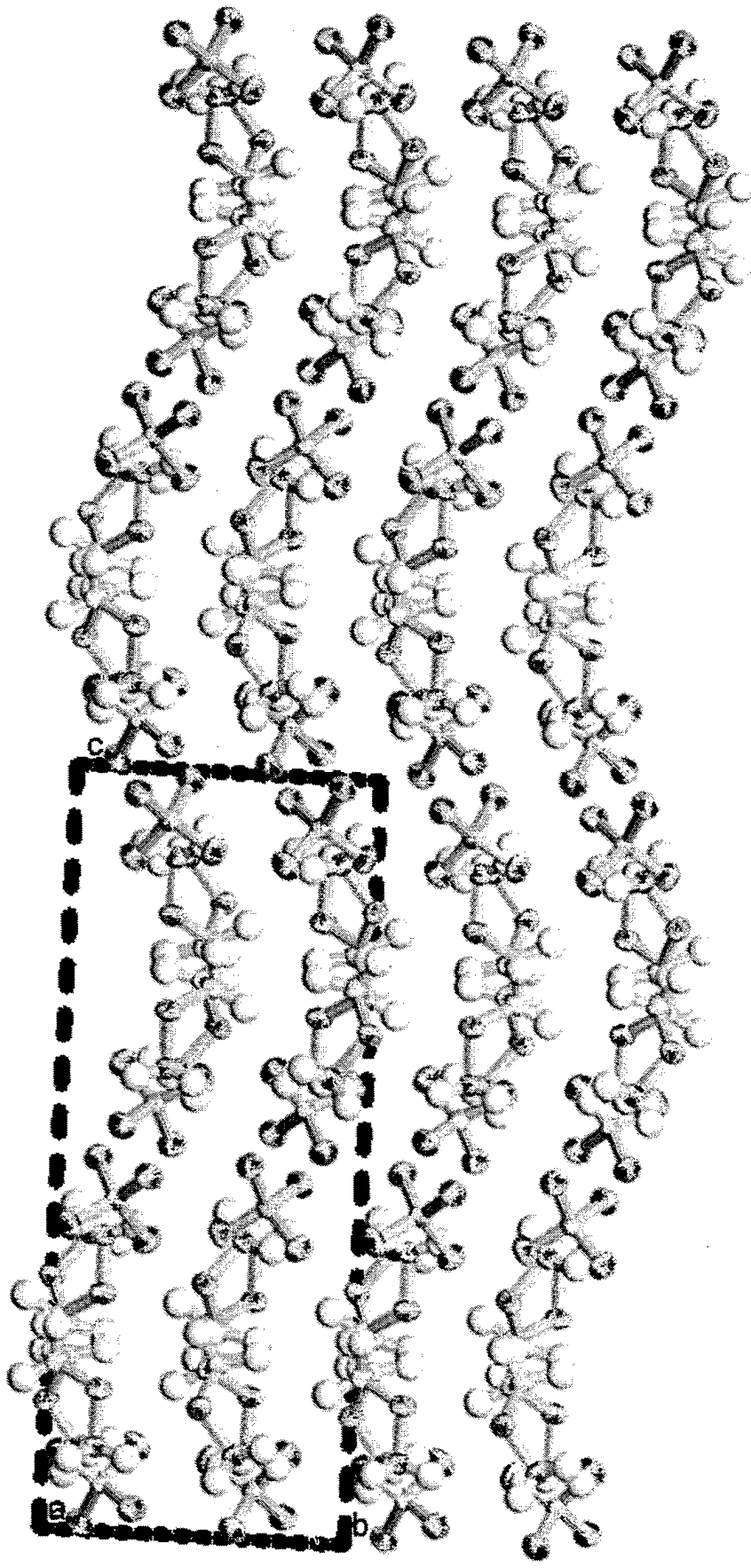
Ionic Liquids



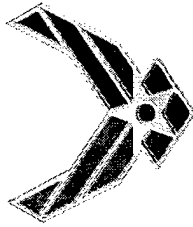
Single crystal x-ray structure of ethylene bisoxymine monoperchlorate. Material has unusual amount of hydrogen bonding present ($\rho = 1.83 \text{ g/cm}^3$!!), but that doesn't explain its extreme sensitivity to impact and friction.



Ionic Liquids

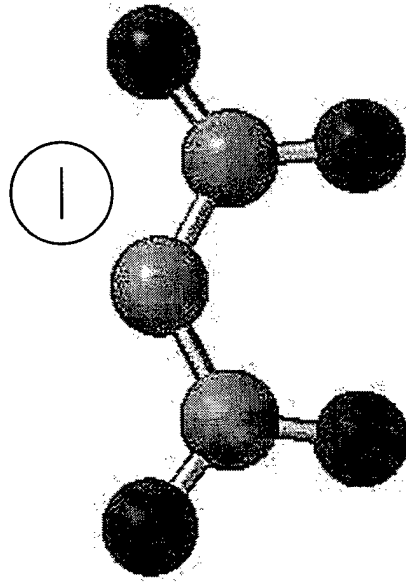


Extended lattice of ethylene bisoxoamine monoperchlorate.

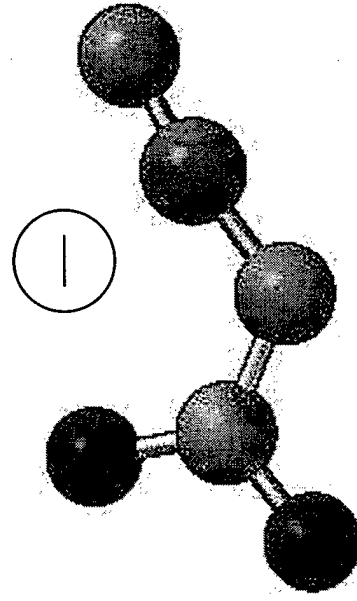


Ionic Liquids

Since its western discovery in the late 1980's, by Jeff Bottaro, the dinitramide anion, $\text{N}(\text{NO}_2)_2^-$ has received tremendous attention as a potential new oxidizing anion for energetic materials. A closely related anion, the nitrocyanamide anion, $\text{N}(\text{NO}_2)(\text{CN})^-$, was discovered in the early 1950's by McKay, and shortly thereafter, Harris investigated many heavy metal salts, as possible replacement initiators. However, it has been virtually ignored since that time.

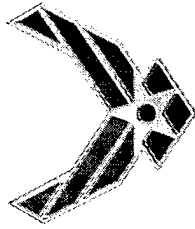


$\text{N}(\text{NO}_2)_2^-$ (dinitramide)

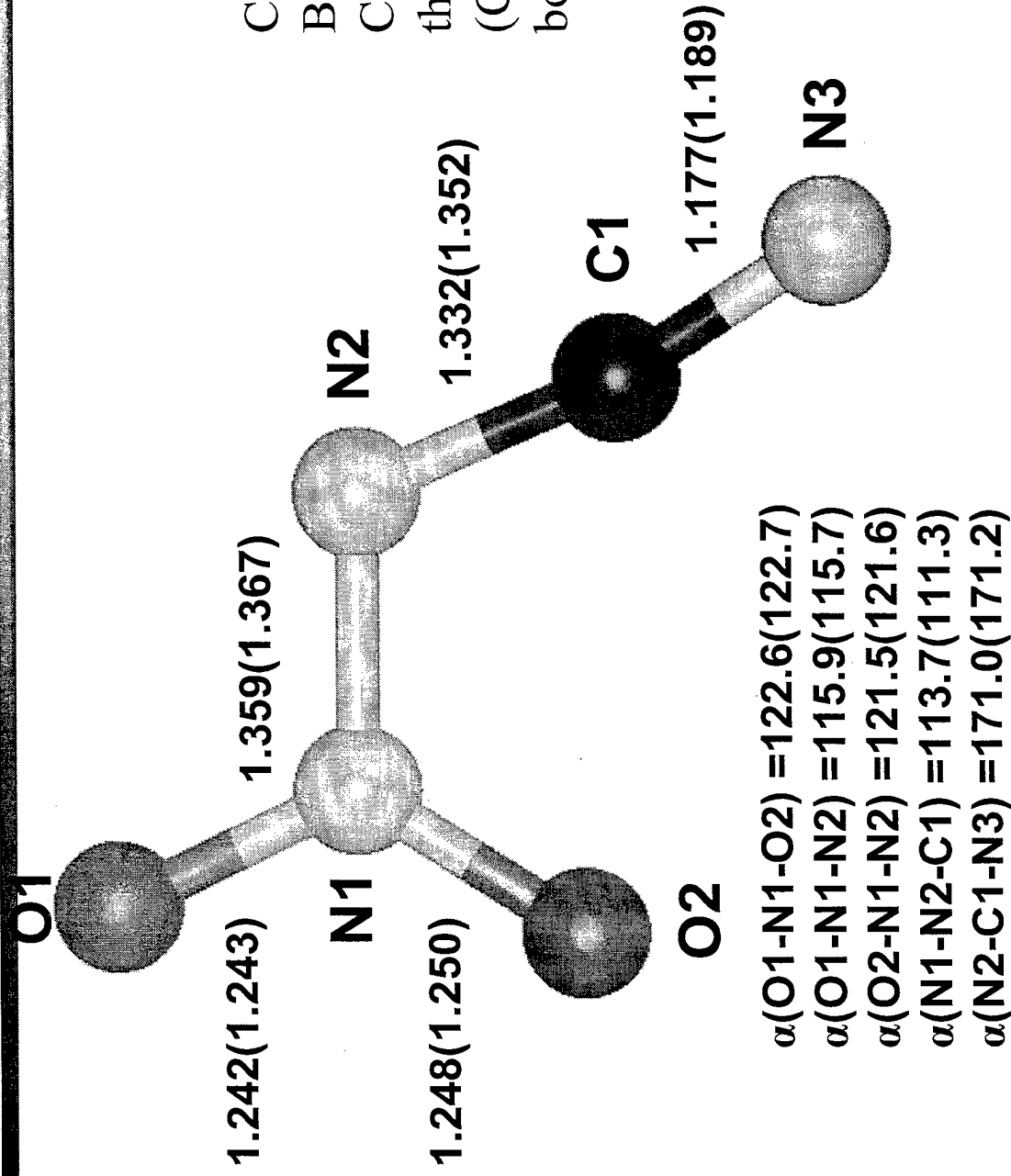


$\text{N}(\text{NO}_2)(\text{CN})^-$ (nitrocyanamide)

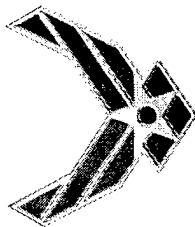
Bottaro, J. L.; Penwell, P. E.; Schmitt, R. J. *Synth. Commun.*, 1991, 21, 945.
McKay, A. F.; Ott, W. L.; Taylor, G. W.; Buchanan, M. N.; Crooker, J. F. *Can. J. Chem.* 1951, 28, 683.; Harris, S. *J. Amer. Chem. Soc.* 1958, 80, 2302.



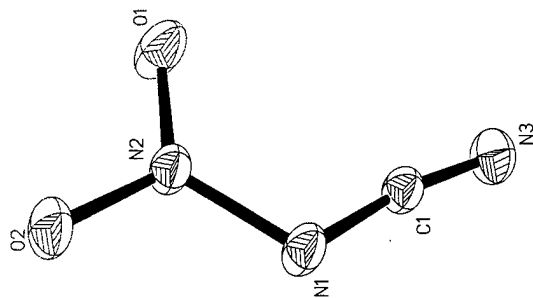
Ionic Liquids



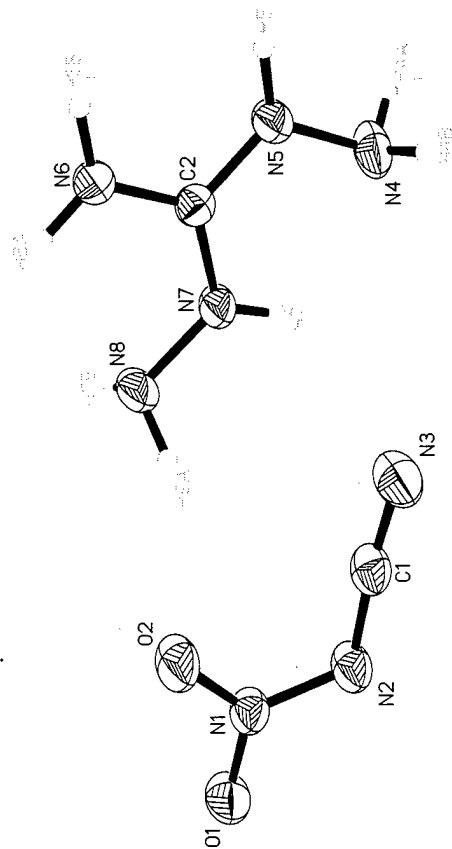
Calculations using B3YLP/cc-pvdz and CCSD(T)/cc-pvdz levels of theory reveal a planar anion (C_s symmetry) with expected bond distances and angles.



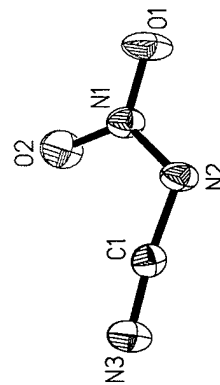
Ionic Liquids



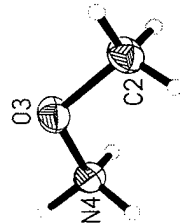
Monomethylhydrazinium nitrocyuanamide

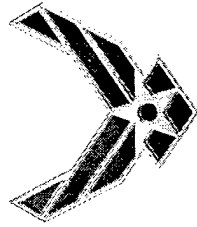


Diaminoguanidinium nitrocyuanamide



Methoxyammonium nitrocyuanamide





Ionic Liquids

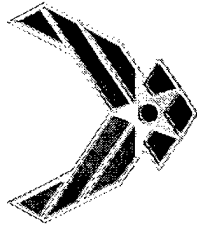


- The syntheses of several nitrocyuanamide salts were accomplished through the metathesis reactions of the appropriate halide salt with silver nitrocyuanamide as Harris reported in 1958.

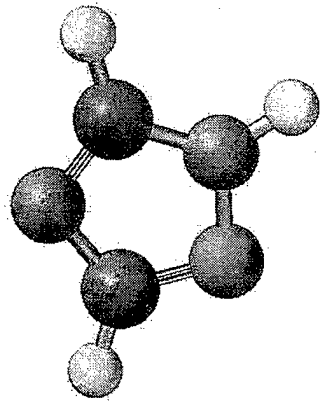


<u>Compound</u>	$\Delta H_f(\text{est})$ Kcal/mole	M.P. ° C	Density g/cm ³ (meas.)	Impact kg-cm (5neg.)	Friction (Newtons) (5 neg.)	TGA % Loss/Day @ 75° C
Hydrazinium nitrocyuanamide	+14	109	1.53	10	76	> 1
Guanidinium nitrocyuanamide	-13	95	1.39	>200	141	0.68
Methoxyammonium nitrocyuanamide	-5	99	1.51	18	149	> 20
Monomethylhydrazinium nitrocyuanamide	+4	57	1.44	>200	>371	1.9
Aminoguanidinium nitrocyuanamide	0	94	1.50	>200	>371	0.9
Diaminoguanidinium nitrocyuanamide	+10	108	1.52	>200	>371	1.6

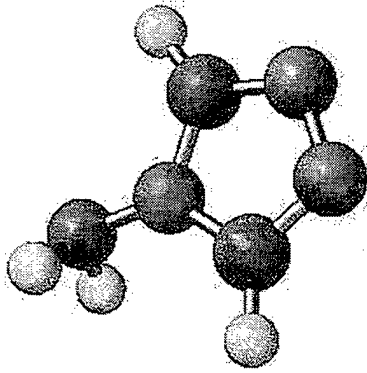
$[\text{NH}_3\text{OH}^+]$ and $[\text{HO}-\text{CH}_2\text{CH}_2-\text{NH}_3^+]$ salts were made, but were not stable at ambient temperatures!



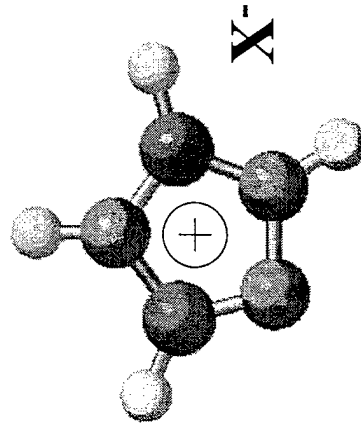
Ionic Liquids



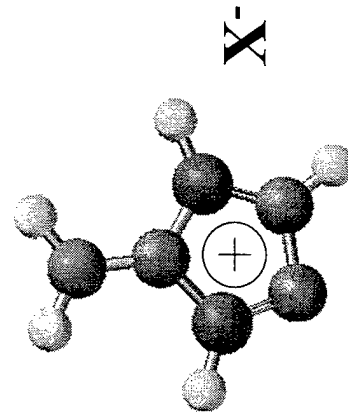
1-H-1,2,4-triazole



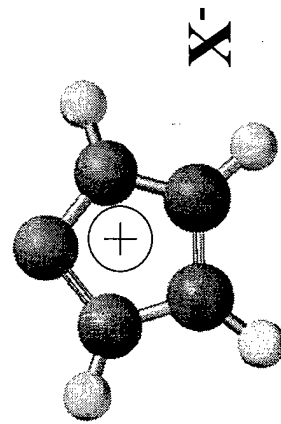
4-amino-1,2,4-triazole



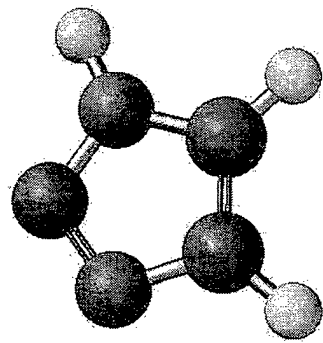
X^-



X^-



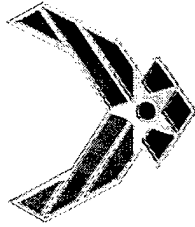
X^-



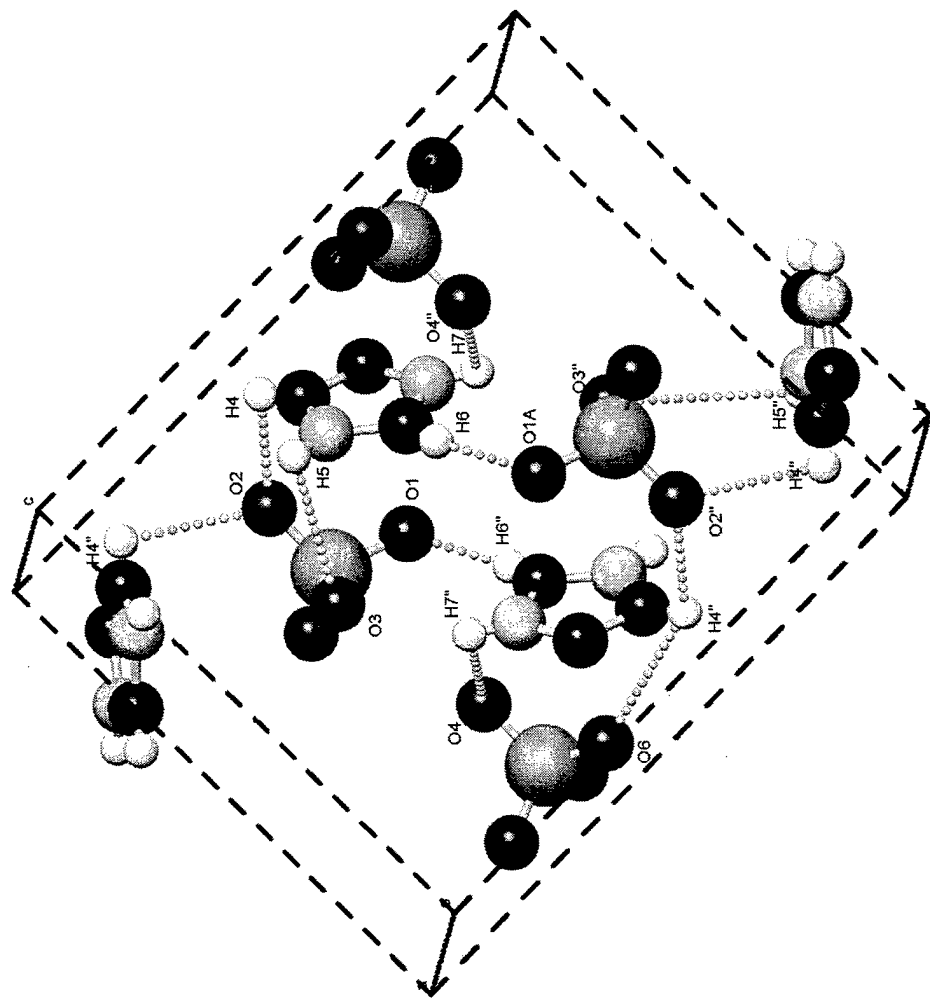
1-H-1,2,3-triazole



Drake, G.W. ; Hawkins, T. ; Brand, A. ; McKay, M. ; Ismail, I. ; Hall, L. ; Vij, A. Prop. Explos. Pyrotech. 2003, 12, 1.

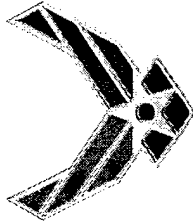


Ionic Liquids



X-ray single crystal diffraction study of 1,2,4-triazolium perchlorate $\rho = 1.96 \text{ g/cm}^3$
It is felt that this is probably the top of the hill density wise for simple heterocycle salts.

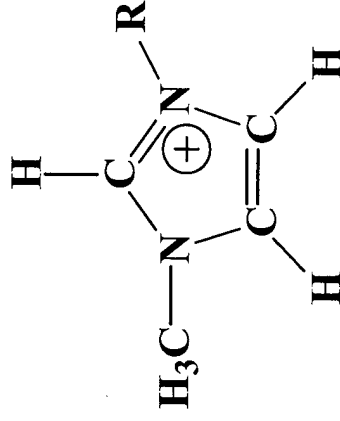
Drake, G.W. ; Hawkins, T. ; Brand, A. ; McKay, M. ; Ismail, I. ; Hall, L. ; Vij, A. Prop. Explos. Pyrotech. 2003, 12, 1.



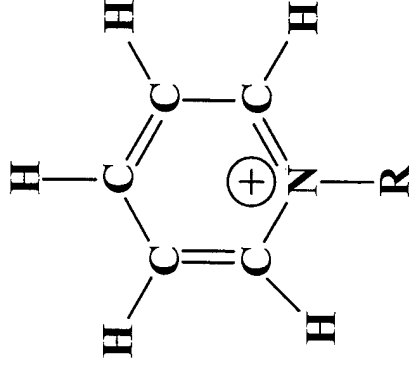
Ionic Liquids



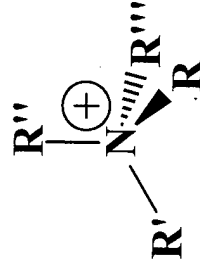
Some major shapes for organic based cations



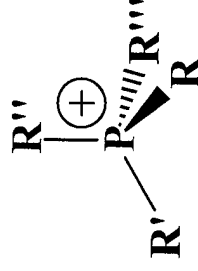
1-methyl-3-alkyl-imidazolium



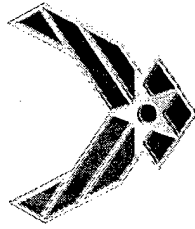
1-alkylpyridinium



Tetraalkylammonium

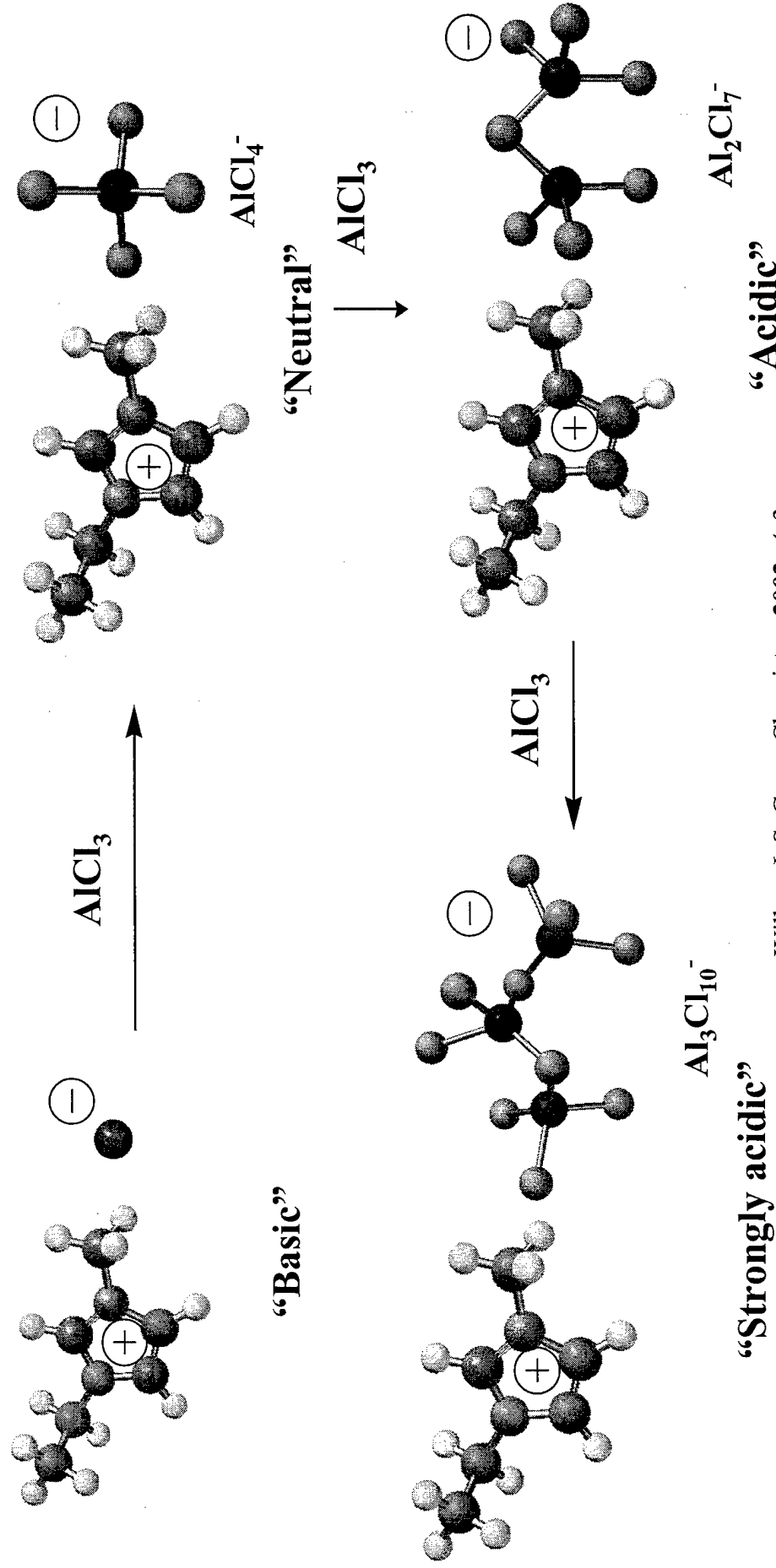


Tetraalkylphosphonium

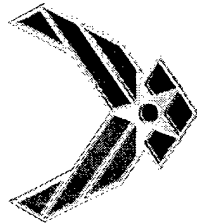


Ionic Liquids

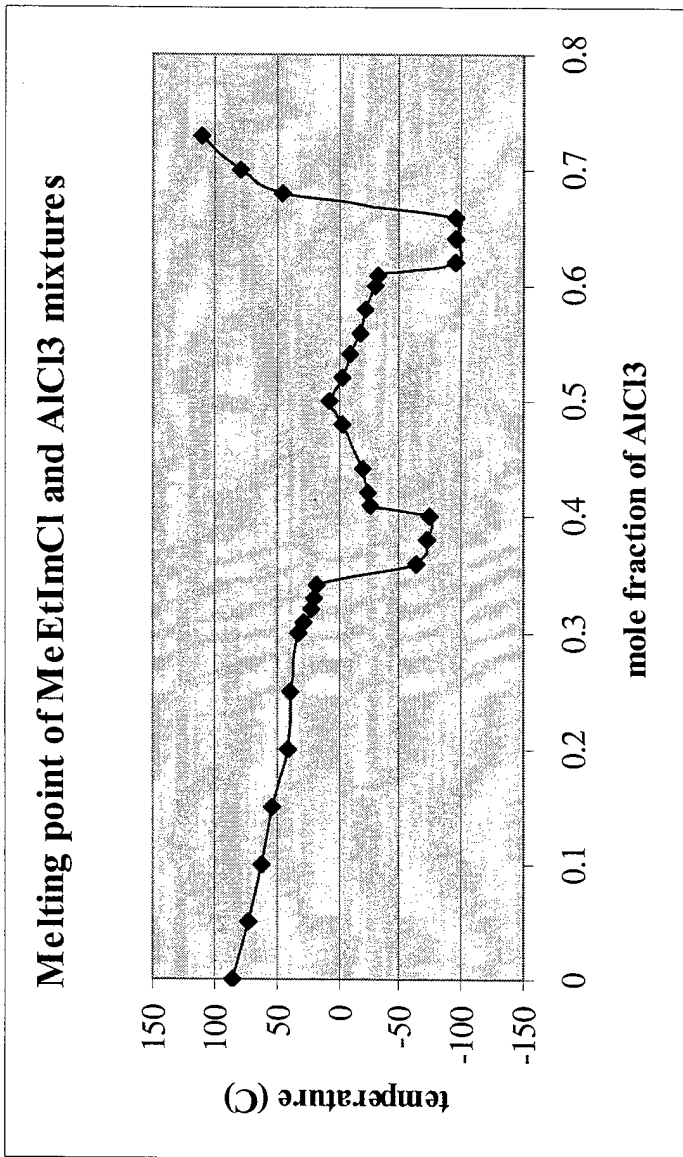
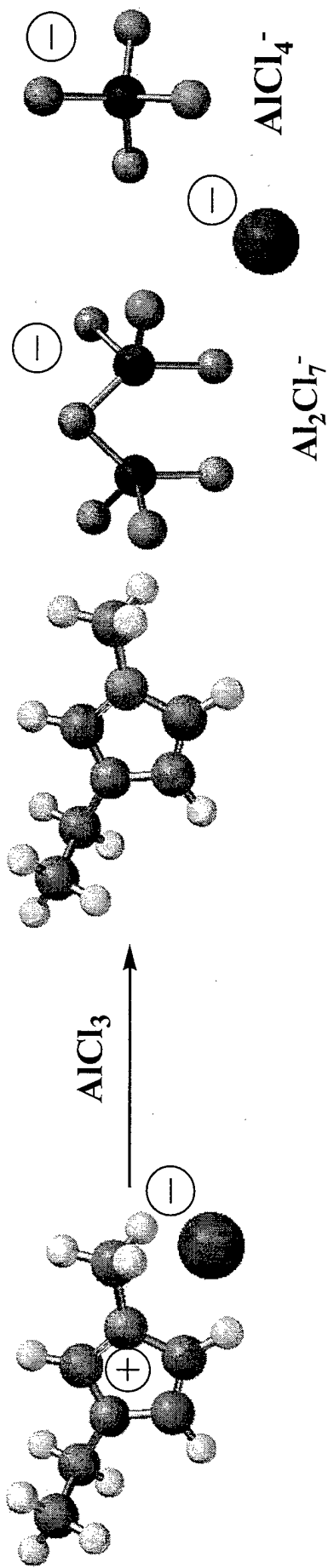
Significant efforts spent on 1-ethyl-3-methyl-imidazolium based systems and aluminum trichloride systems. More complex than originally thought as AlCl_3 and Cl^- have an equilibrium based on their respective concentrations.



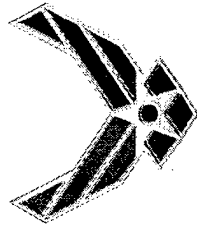
Wilkes, J. S. Green Chemistry 2002, 4, 3.



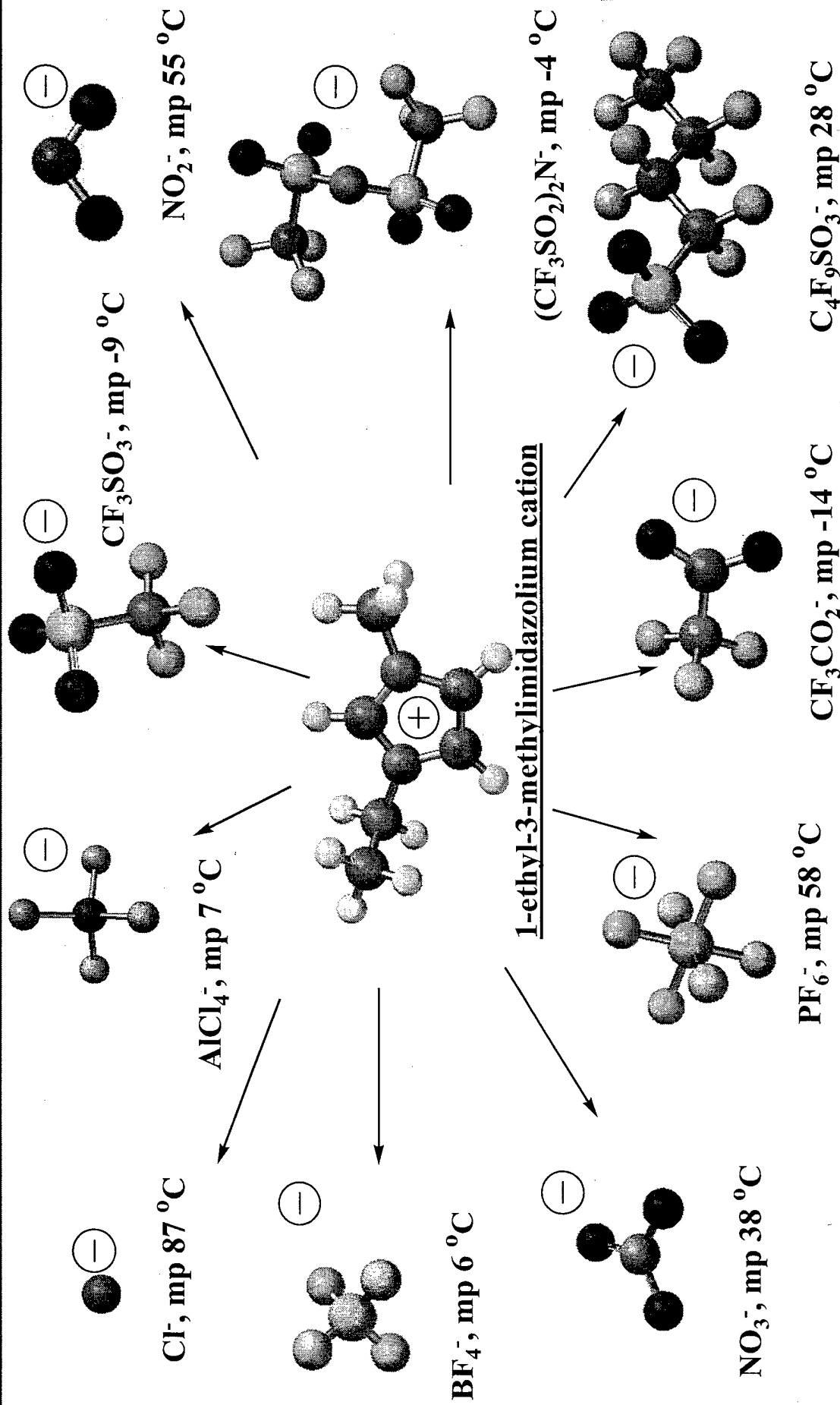
Ionic Liquids



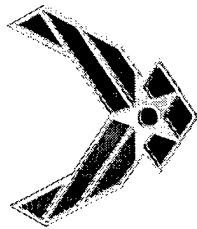
Fannin, A. ; Floreani, D. ; King, L. ; Landers, J. ; Piersma, B. ; Stetch, D. ; Vaughn, R. ; Wilkes, J. ; Williams, J. J. *J. Phys. Chem.* **1984**, *88*, 2614.



Ionic Liquids

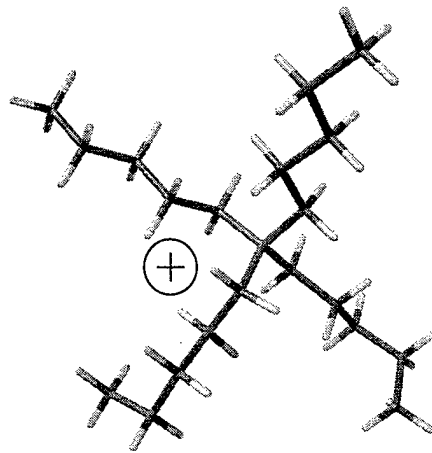


Wasserscheid, P.; Keim, W. *Angew. Chem. Int. Ed. Engl.* **2000**, 39, 3772. Wasserscheid, P., Welton, T. (eds.) *Ionic Liquids in Synthesis* Wiley-VCH, FRG, 2003. Seddon, K.R.; Holbrey, J. D. *Clean Products and Processes* **1999**, 1, 223. Rogers, R.; Seddon, K. (eds.) *Ionic Liquids* A.C.S. Symp. Ser. 818 2002 A.C.S. Publ. Co.



Ionic Liquids

Substituted ammonium salts $R_4N^+X^-$ - Variations in melting point based on cation structure.



Tetra-n-pentylammonium cation

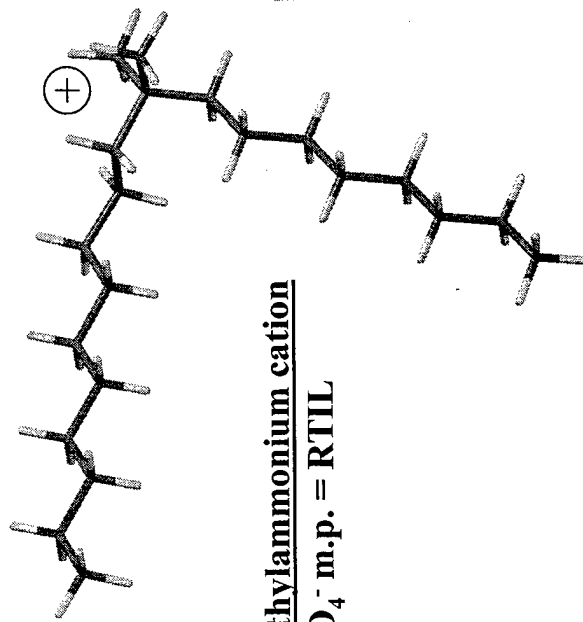
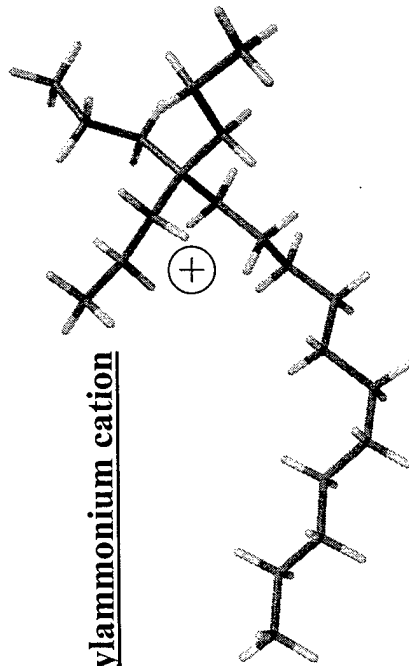
Br^- m.p. = 101 °C

ClO_4^- m.p. = 118 °C

Tris-(n-propyl)-undecylammonium cation

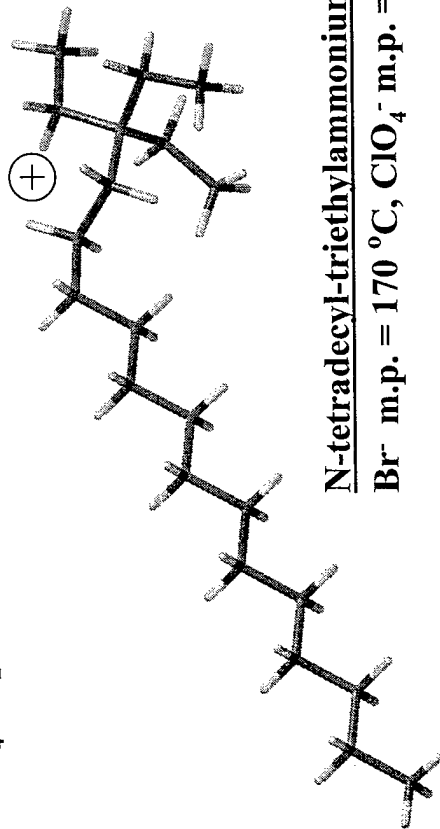
Br^- m.p. = 67 °C

ClO_4^- m.p. = 65 °C



N-decyl-n-octyl-dimethylammonium cation

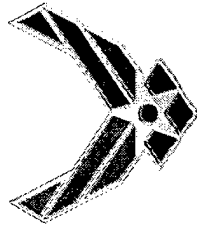
Br^- m.p. = RTIL, ClO_4^- m.p. = RTIL



N-tetradecyl-triethylammonium cation

Br^- m.p. = 170 °C, ClO_4^- m.p. = 152 °C

Gordon, J. E. ; SubbaRao, G. N. J. Amer. Chem. Soc. 1978, 100, 7445.



Ionic Liquids

Substituted ammonium salts $[R_4N^+][X^-]$ Recently work has been done by using more desirable anions.

<u>Substituted Ammonium Salt</u>	<u>M.P.</u> (° C)	<u>Density</u> (g/cm ³)	<u>Viscosity</u> (cp)	<u>Λ</u> (Ω^{-1} cm ² /mole)
$[(n-C_6H_{13})(CH_3)_3N^+][N(SO_2CF_3)_2]^-$	-74 (g)	1.33	153	1.4
$[(n-C_7H_{15})(CH_3)_3N^+][N(SO_2CF_3)_2]^-$	-73 (g)	1.28	153	1.4
$[(n-C_8H_{17})(CH_3)_3N^+][N(SO_2CF_3)_2]^-$	-73(g)	1.27	181	1.3
$[(n-C_6H_{13})(CH_3CH_2)_3N^+][N(SO_2CF_3)_2]^-$	20	1.27	167	2.5
$[(n-C_7H_{15})(CH_3CH_2)_3N^+][N(SO_2CF_3)_2]^-$	-79	1.26	75	1.9
$[(n-C_8H_{17})(CH_3CH_2)_3N^+][N(SO_2CF_3)_2]^-$	-74	1.25	202	1.3
$[(n-C_6H_{13})(n-C_4H_9)_3N^+][N(SO_2CF_3)_2]^-$	26	1.15	595	0.8
$[(n-C_7H_{15})(n-C_4H_9)_3N^+][N(SO_2CF_3)_2]^-$	-67	1.17	606	0.8
$[(n-C_8H_{17})(n-C_4H_9)_3N^+][N(SO_2CF_3)_2]^-$	-63	1.12	574	0.7
$[(n-C_7H_{15})(Et)_3N^+][N(SO_2CF_3)_2]^-$	-82	1.27	362	1.2
$[(n-C_8H_{17})(n-C_4H_9)_3N^+][OSO_2CF_3]^-$	-57	1.02	2030	0.07

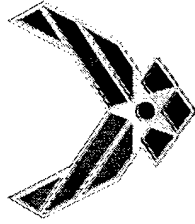
-most have very low glass points

-densities decrease as expected

-viscosity increases dramatically with increasing alkyl length

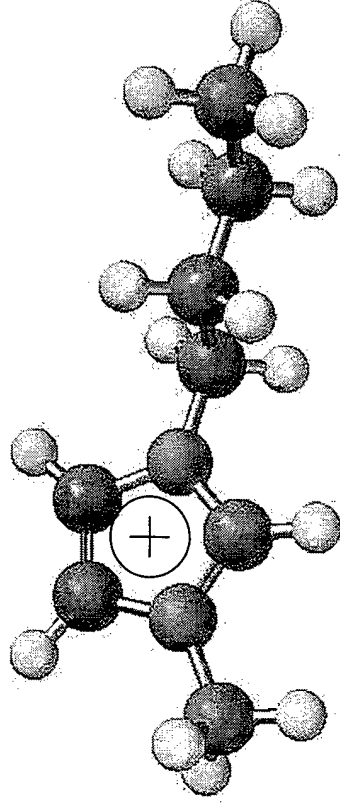
-conductivity decreases with cation size (mobility issue)

Sun, J. ; Forsyth, M. ; MacFarlane, D. R. J. Phys. Chem. B 1998, 102, 8858.

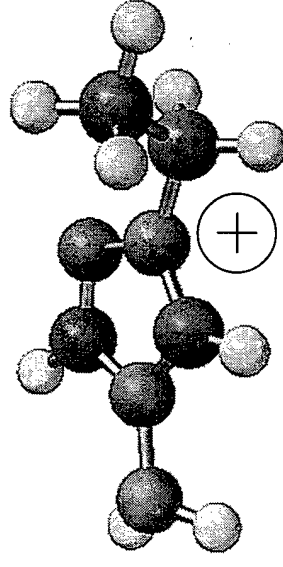


Ionic Liquids

Most ionic liquids are based upon imidazolium rings and “heavy” or “dead” anions. We felt that we could use the shape of the cation and the poor fit idea to make much more energetic salts in a simple manner.

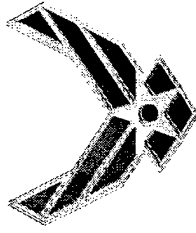


1-n-butyl-3-methyl imidazolium
cation

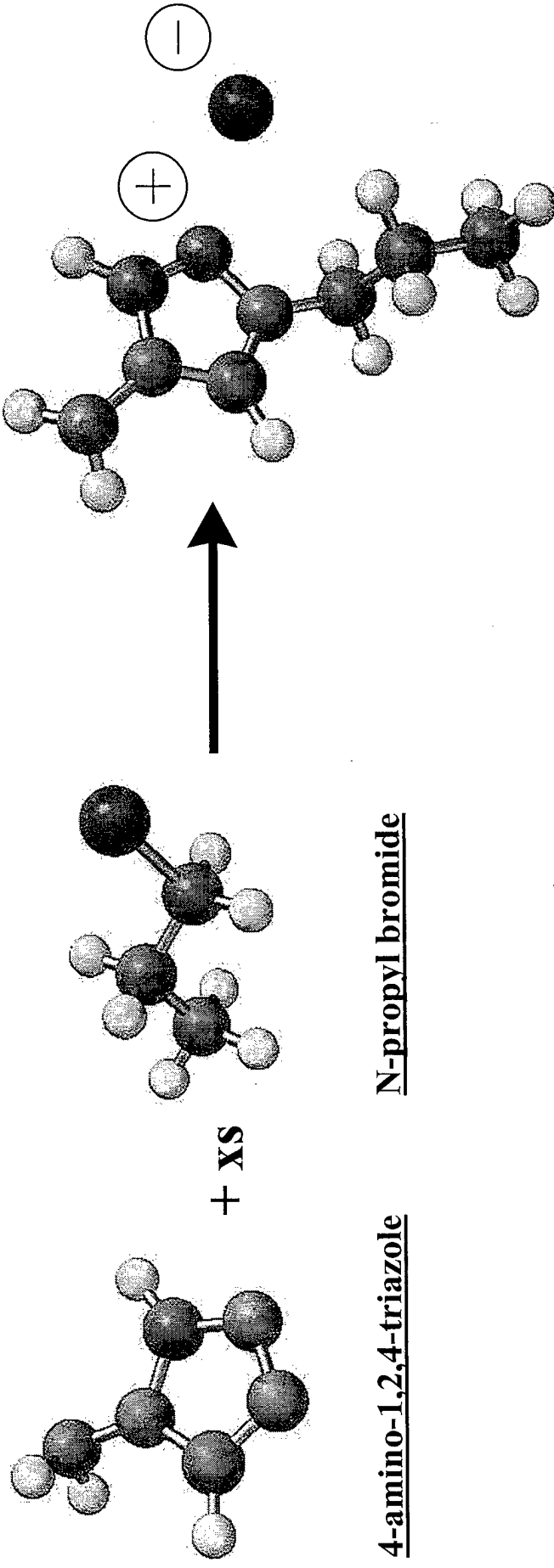


1-ethyl-4-amino-1,2,4-
triazolium cation

These new ionic liquids have similar shapes and physical properties,
BUT higher ΔH_f , higher densities, and better oxygen balances.

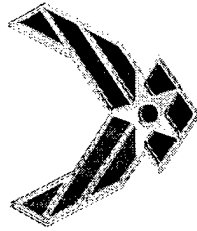


Ionic Liquids

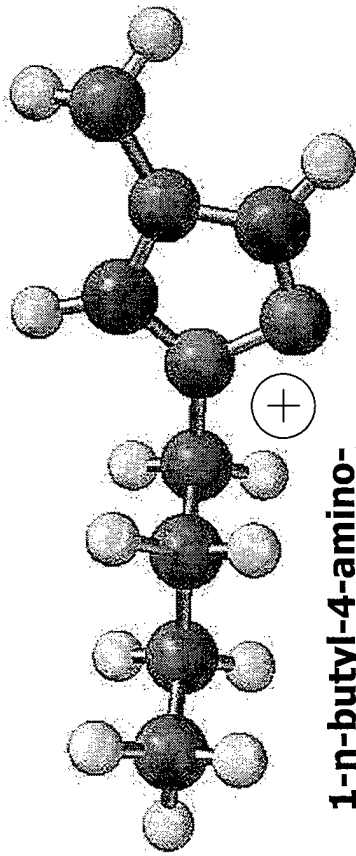


Synthesis is from commercial materials
High yield simple isolation has been known
in literature for quite some time.

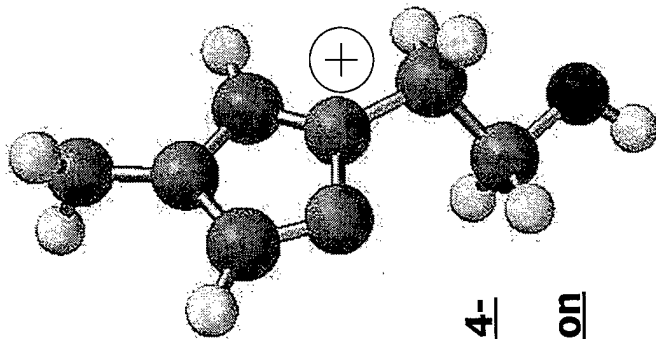
Scriven; Keay; Goe; Astleford J. Org. Chem. **1989**, *54*, 731.



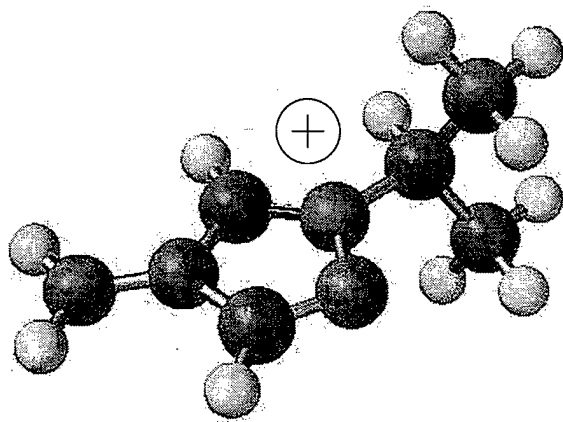
Ionic Liquids



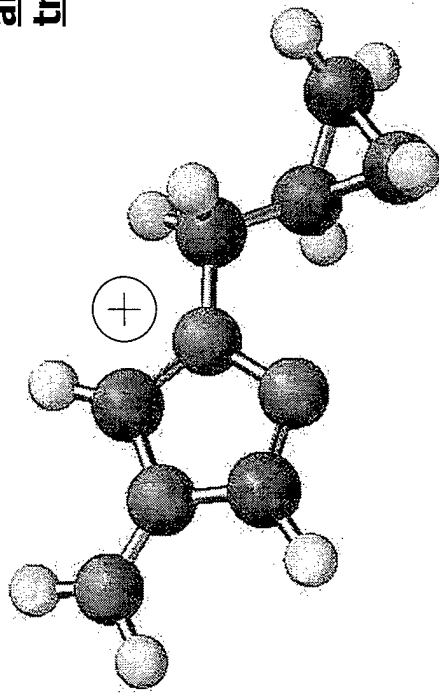
1-n-butyl-4-amino-1,2,4-triazolium cation



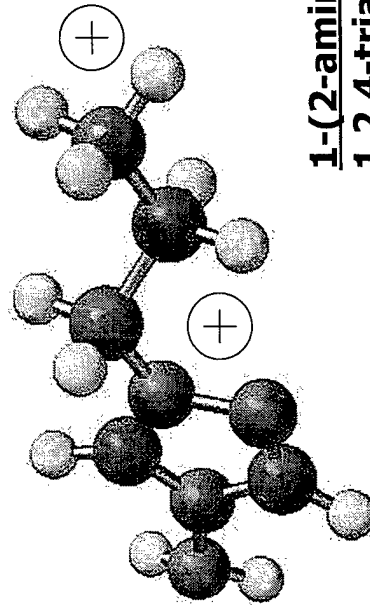
1-(2-ethanol)-4-amino-1,2,4-triazolium cation



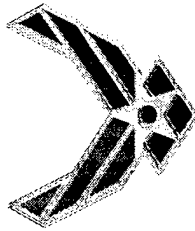
1-isopropyl-4-amino-1,2,4-triazolium cation



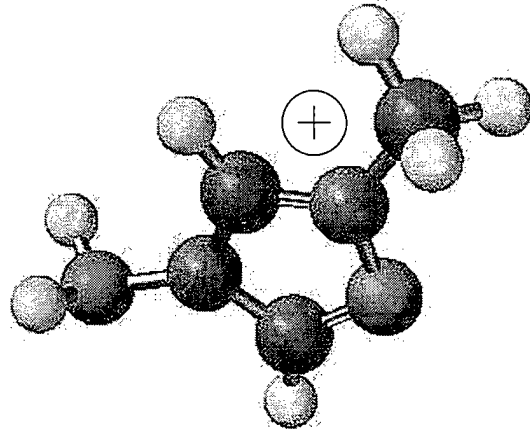
1-methylcyclopropyl-4-amino-1,2,4-triazolium cation



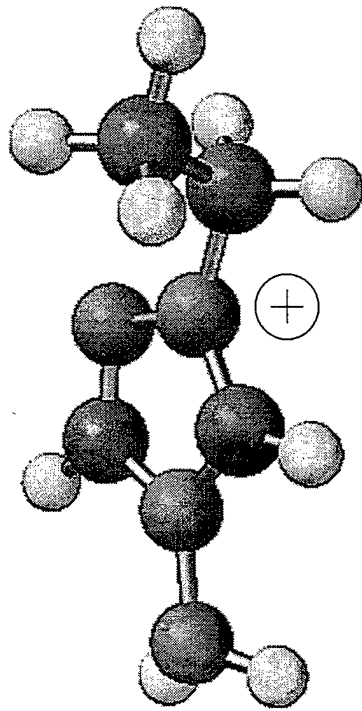
1-(2-aminoethyl)-4-amino-1,2,4-triazolium dication



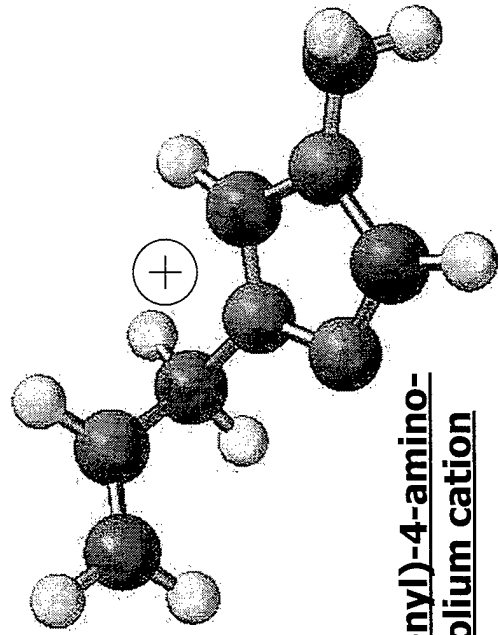
Ionic Liquids



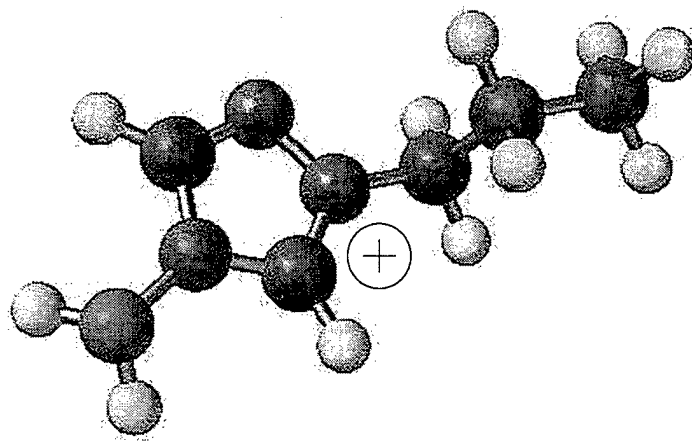
1-methyl-4-amino-1,2,4-triazolium cation



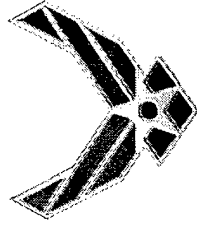
1-ethyl-4-amino-1,2,4-triazolium cation



1-(2-propenyl)-4-amino-1,2,4-triazolium cation



1-n-propyl-4-amino-1,2,4-triazolium cation



Ionic Liquids



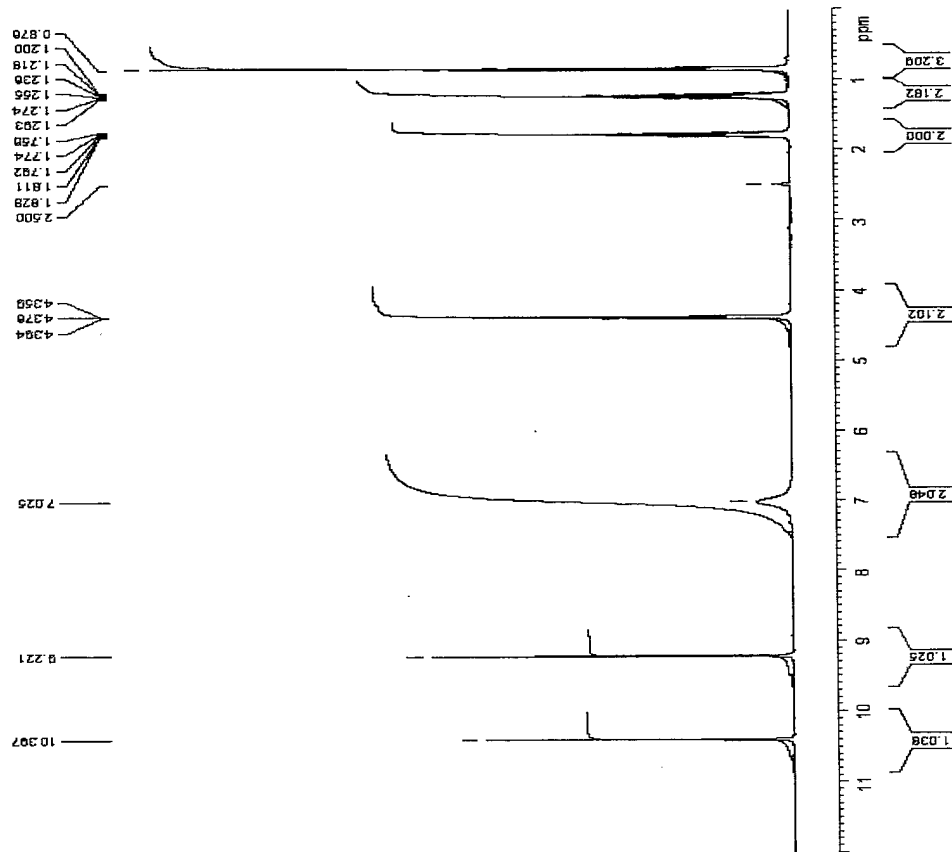
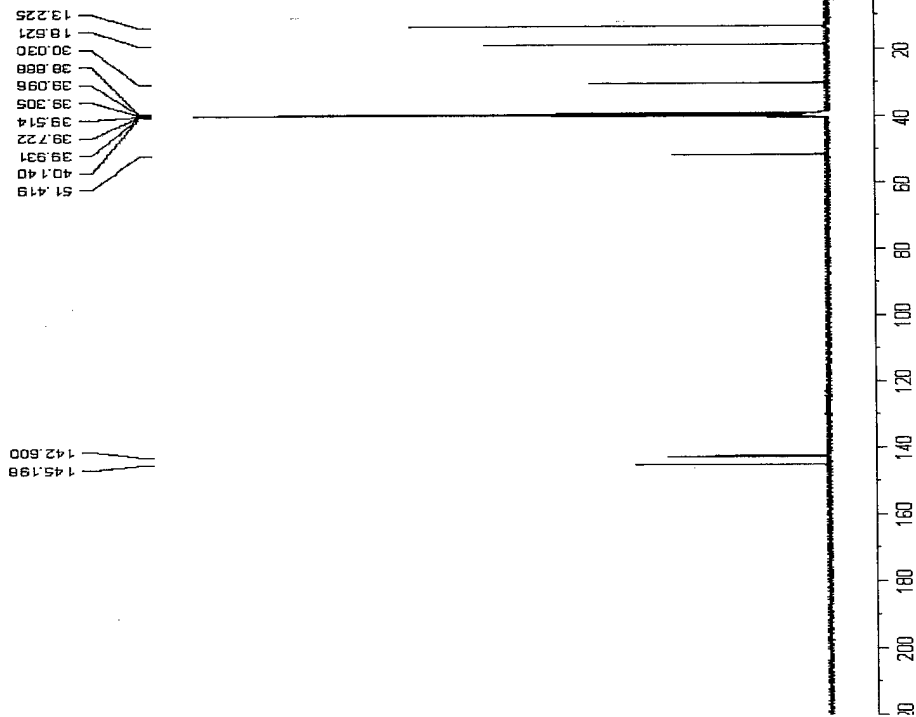
Physical properties of 1-n-alkyl substituted-4-amino-1,2,4-triazolium bromides.

- increasing melting points with increasing molecular weights,
- decomposition onsets that are relatively low
- densities decrease with increasing alkyl chain length.

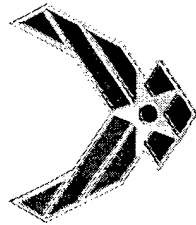
Substituted 4AT salts	m.p. (°C)	dec. onset (°C)	density (g/cm ³)
1-ethyl	63°	110	1.69
1-n-propyl	60°	120	1.56
1-isopropyl	90°	110	1.60
1-butyl	48°	130	1.46
1-n-pentyl	54°	130	1.37
1-n-hexyl	76°	120	1.34
1-n-heptyl	94°	120	1.30
1-n-octyl	80°	135	1.27
1-n-nonyl	81°	140	1.26
1-n-decyl	90°	135	1.23



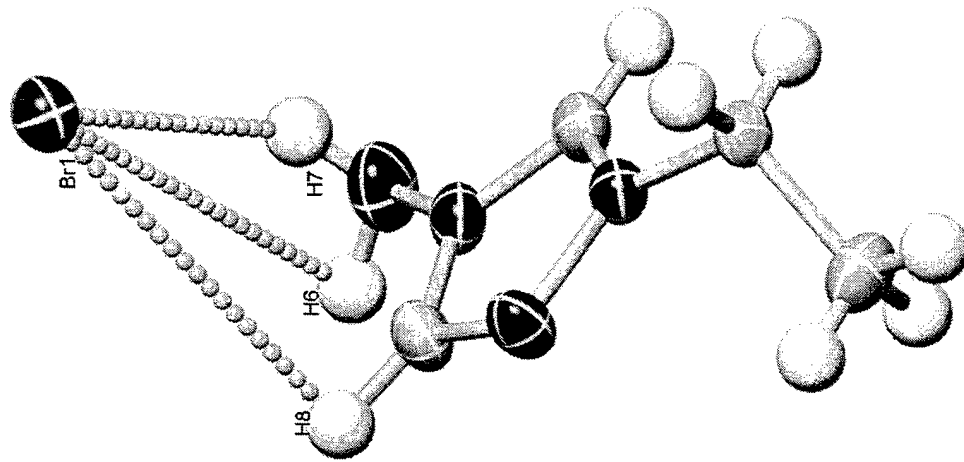
Ionic Liquids

carbon of 1-*n*-butyl-4-amino-1,2,4-triazolium bromide solid in d₆-DMSO

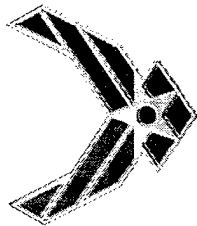
¹H(left) and ¹³C nmr spectra of 1-butyl-4-amino-1,2,4-triazolium bromide.



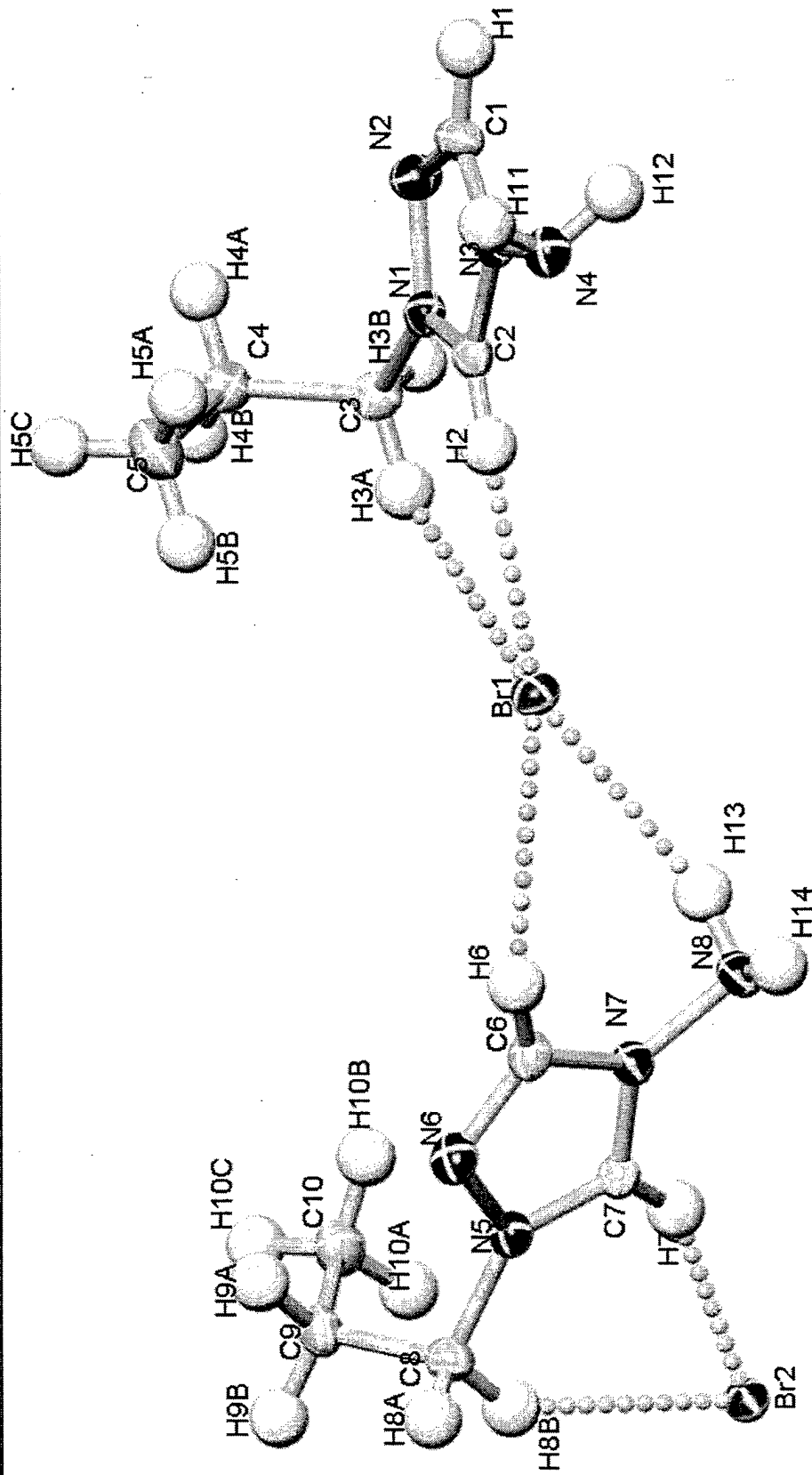
Ionic Liquids



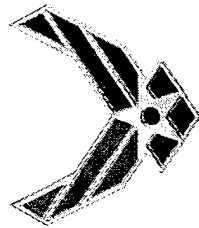
Single x-ray diffraction study of 1-ethyl-4-amino-1,2,4-triazolium bromide.



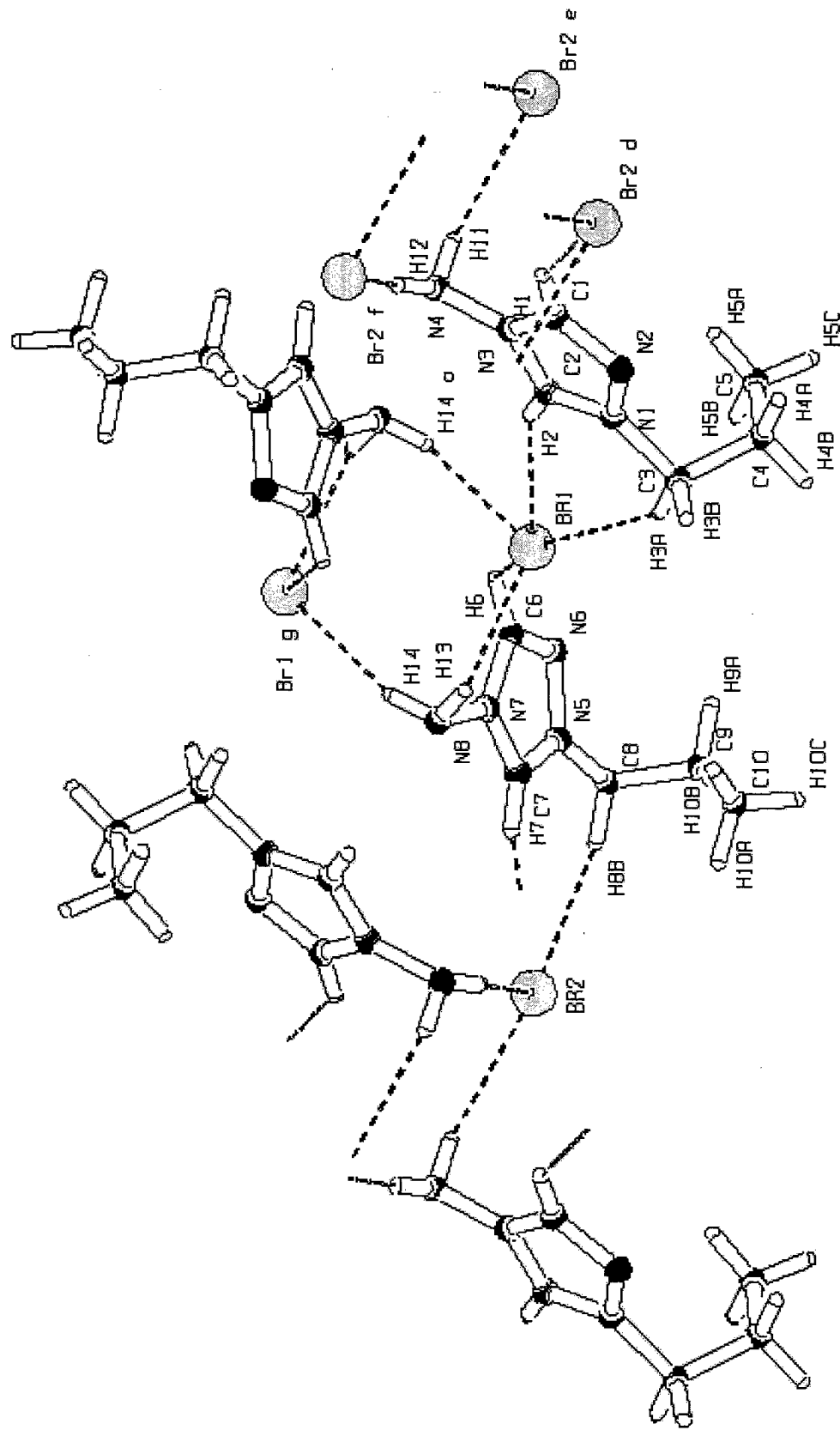
Ionic Liquids



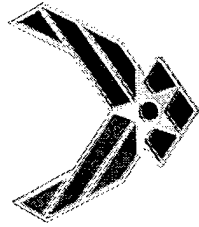
Single crystal x-ray diffraction study of 1-n-propyl-4-amino-1,2,4-triazolium bromide showing significant hydrogen bond contacts.



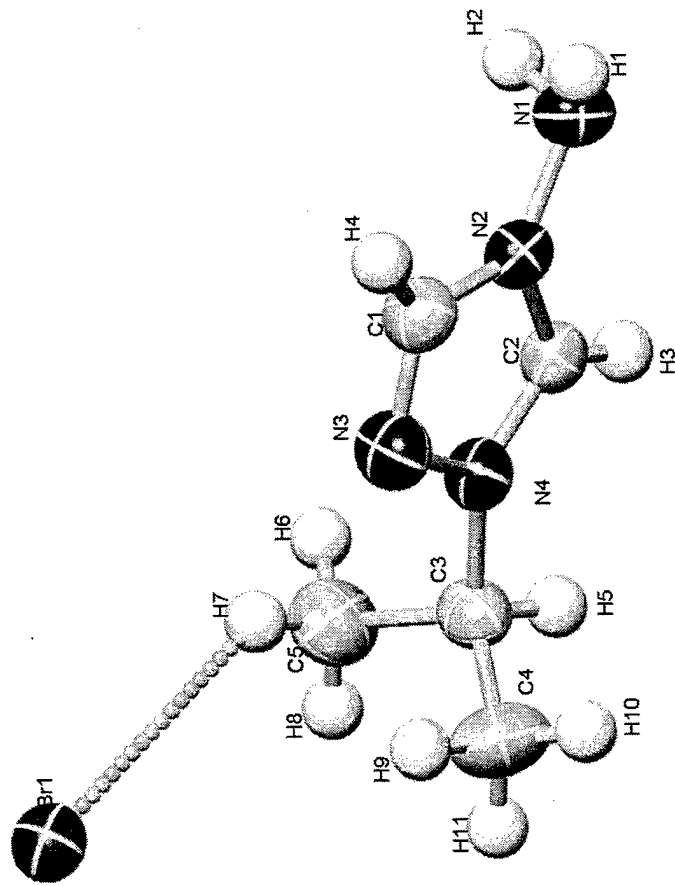
Ionic Liquids



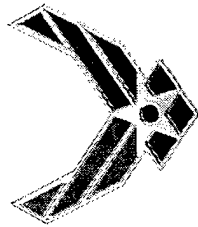
Hydrogen bond contacts in solid 1-n-propyl-4-amino-1,2,4-triazolium bromide



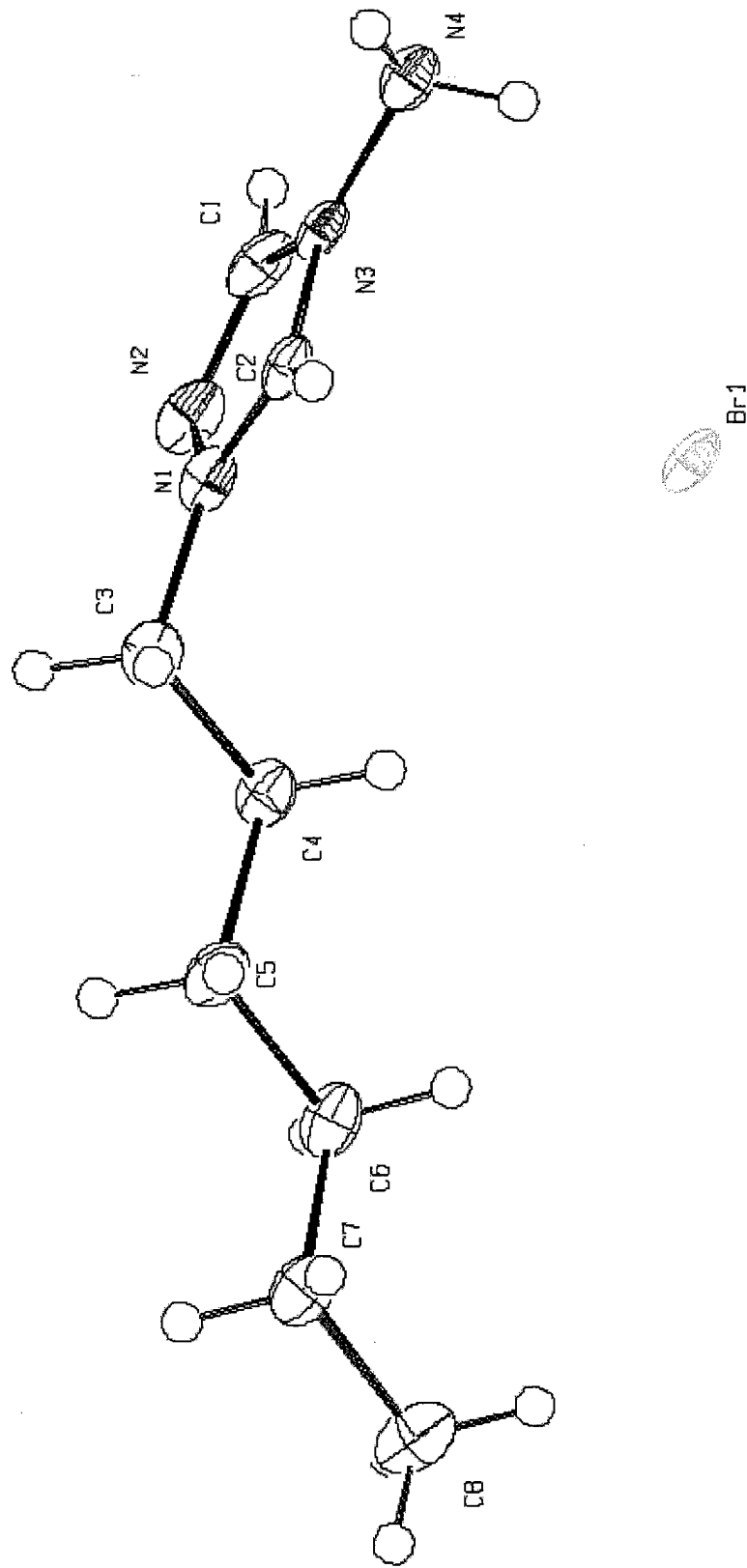
Ionic Liquids



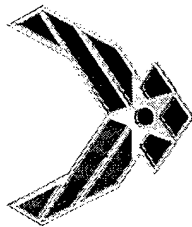
Single crystal x-ray diffraction structure of 1-isopropyl-4-amino-1,2,4-triazolium bromide.



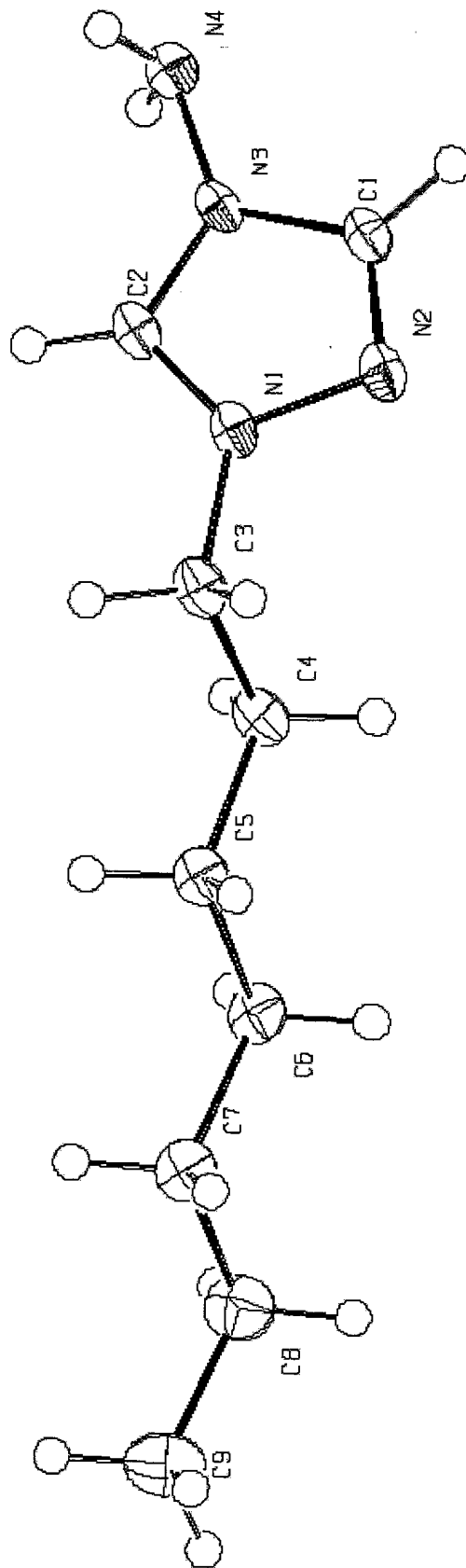
Ionic Liquids



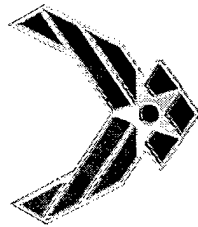
Single crystal x-ray diffraction study of 1-hexyl-4-amino-1,2,4-triazolium bromide.



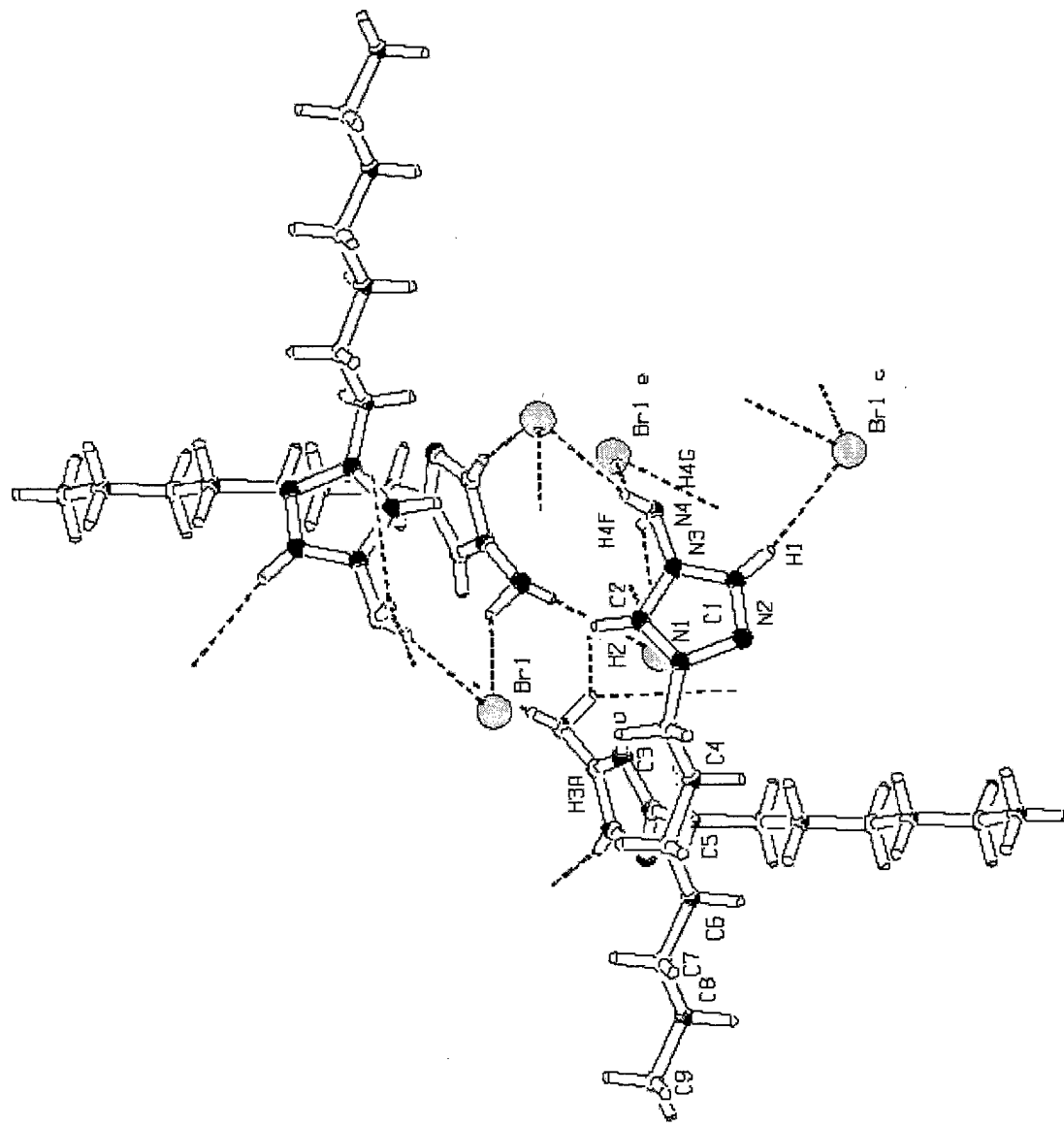
Ionic Liquids



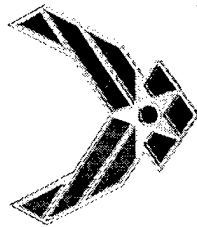
Single crystal x-ray diffraction study of 1-heptyl-4-amino-1,2,4-triazolium bromide.



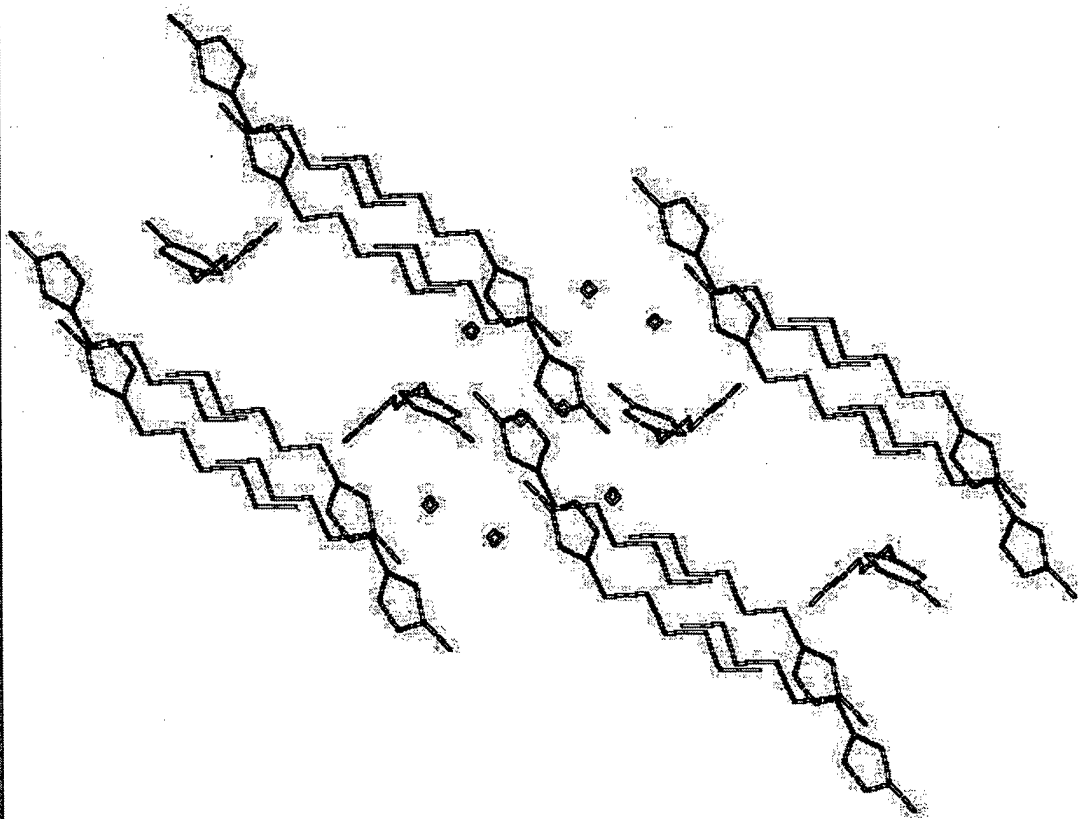
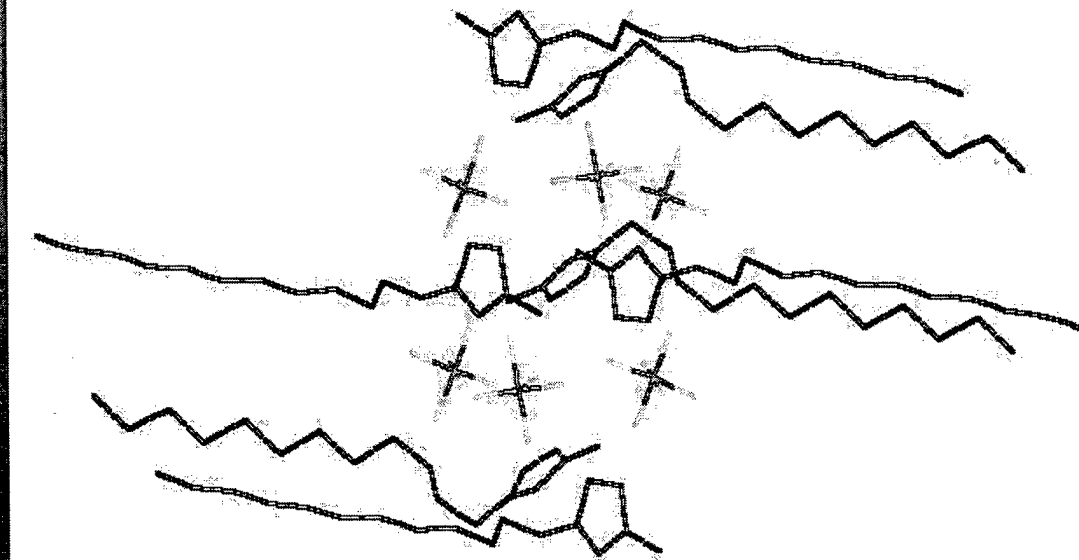
Ionic Liquids



Hydrogen bond contacts in 1-heptyl-4-amino-1,2,4-triazolium bromide



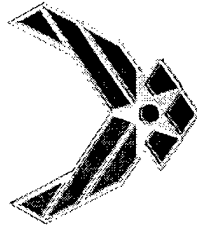
Ionic Liquids



1-dodecyl-3-methylimidazolium hexafluorophosphate*

1-hexyl-4-amino-1,2,4-triazolium bromide[#]

*Gordon, C. M.; Holbrey, J. D.; Kennedy, A. R.; Seddon, K. R. *J. Mater. Chem.* **1998**, *8*, 2627. [#]Drake, G. W.; Hawkins, T. W.; Tollison, K.; Hall, L.; Vij, A. 2003 manuscript in progress.

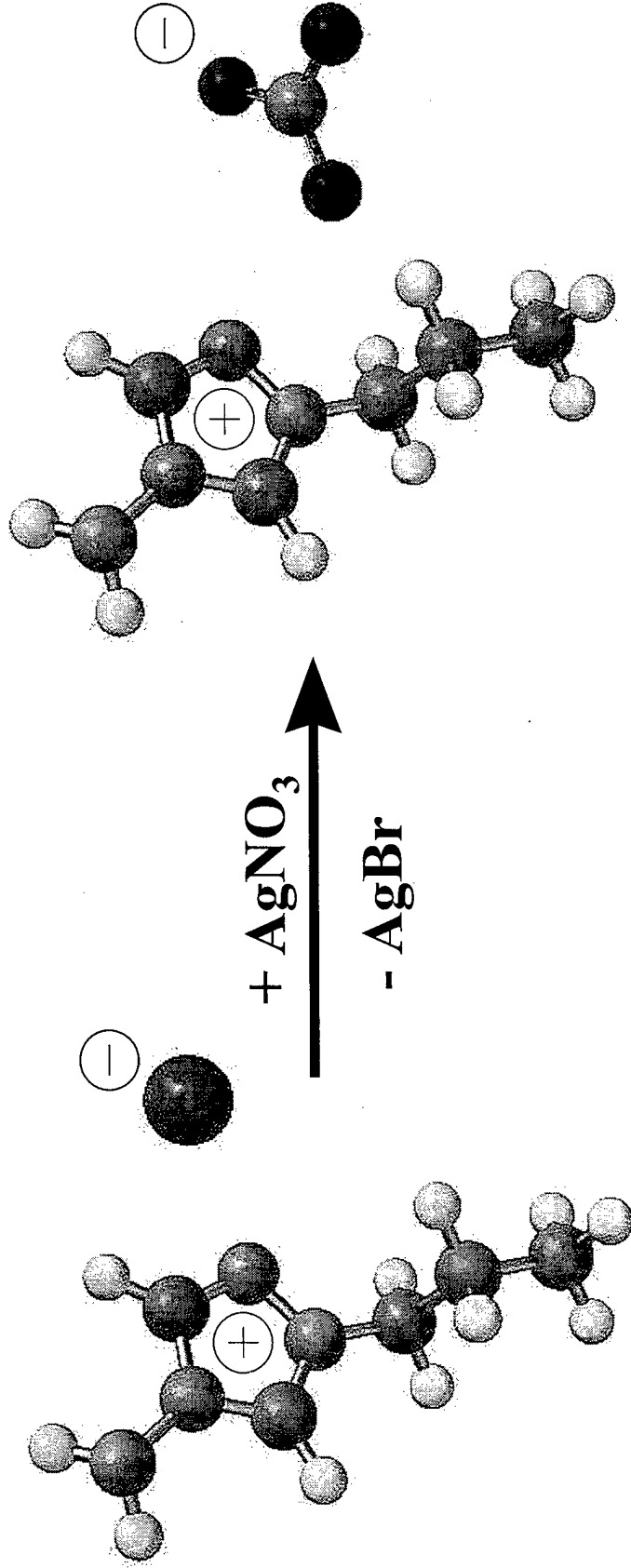


Ionic Liquids

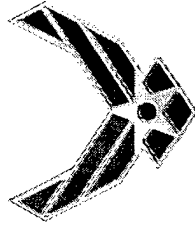


But halides are only the start...

Nitrates were best made through silver nitrate metathesis in methanol.



This route led to the best materials as the silver bromide was easily removed.

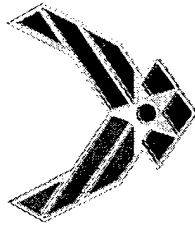


Ionic Liquids



1-substituted-4-amino-1,2,4-triazolium nitrate salts are more stable.

<u>Salt</u>	<u>melting point(°C)</u>	<u>decomp onset(°C)</u>	<u>$\rho(\text{g}/\text{cm}^3, \text{est.})$</u>
1-methyl	54	185	1.57
1-ethyl	5	185	1.39 (1.38)
1-n-propyl	34	190	1.35
1-isopropyl	53	175	1.37 (1.43)
1-n-butyl	-25 (g)	190	1.31
1-(2-ethanol)	-50 (g)	180	1.48
1-methylcyclopropyl	56	190	1.36 (1.44)
1-(2-propenyl)	10	165	1.23
1-n-pentyl	26	170	1.29
1-n-hexyl	-2	160	1.26
1-n-heptyl	31	160	1.24
1-n-octyl	29	170	1.22
1-n-nonyl	53	175	1.20
1-n-decyl	49	185	1.18



Ionic Liquids



Sample: 1-PROPYL-4-AT NITRATE

Size: 1.9000 mg

Method: greg

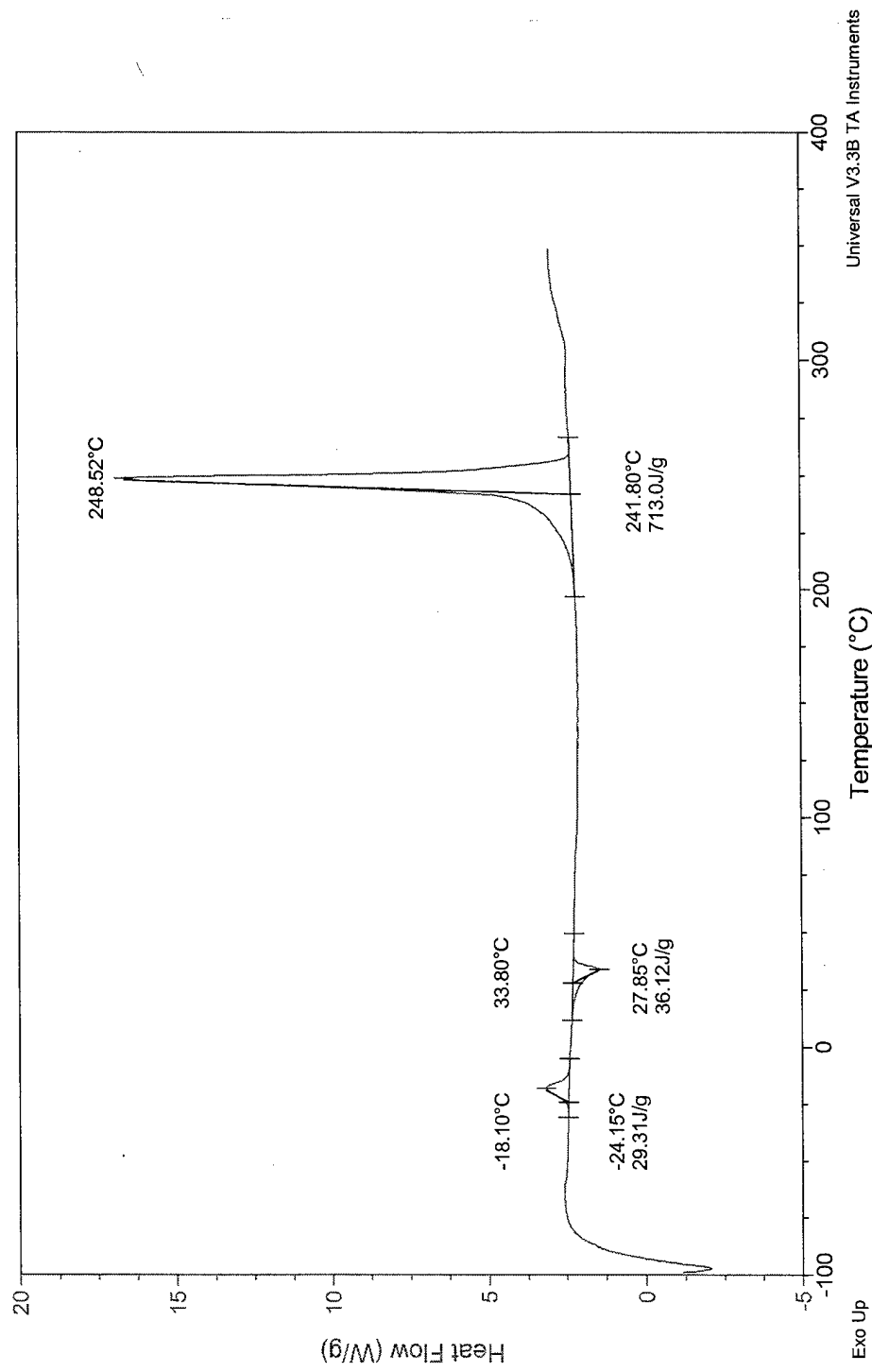
Comment: 10C/min/10ml/minhermeticalpans

DSC

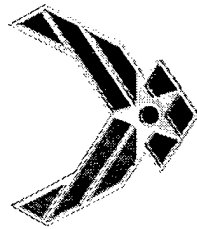
File: C:\...files from old DSC\4at propyl no3

Operator: DRAKE

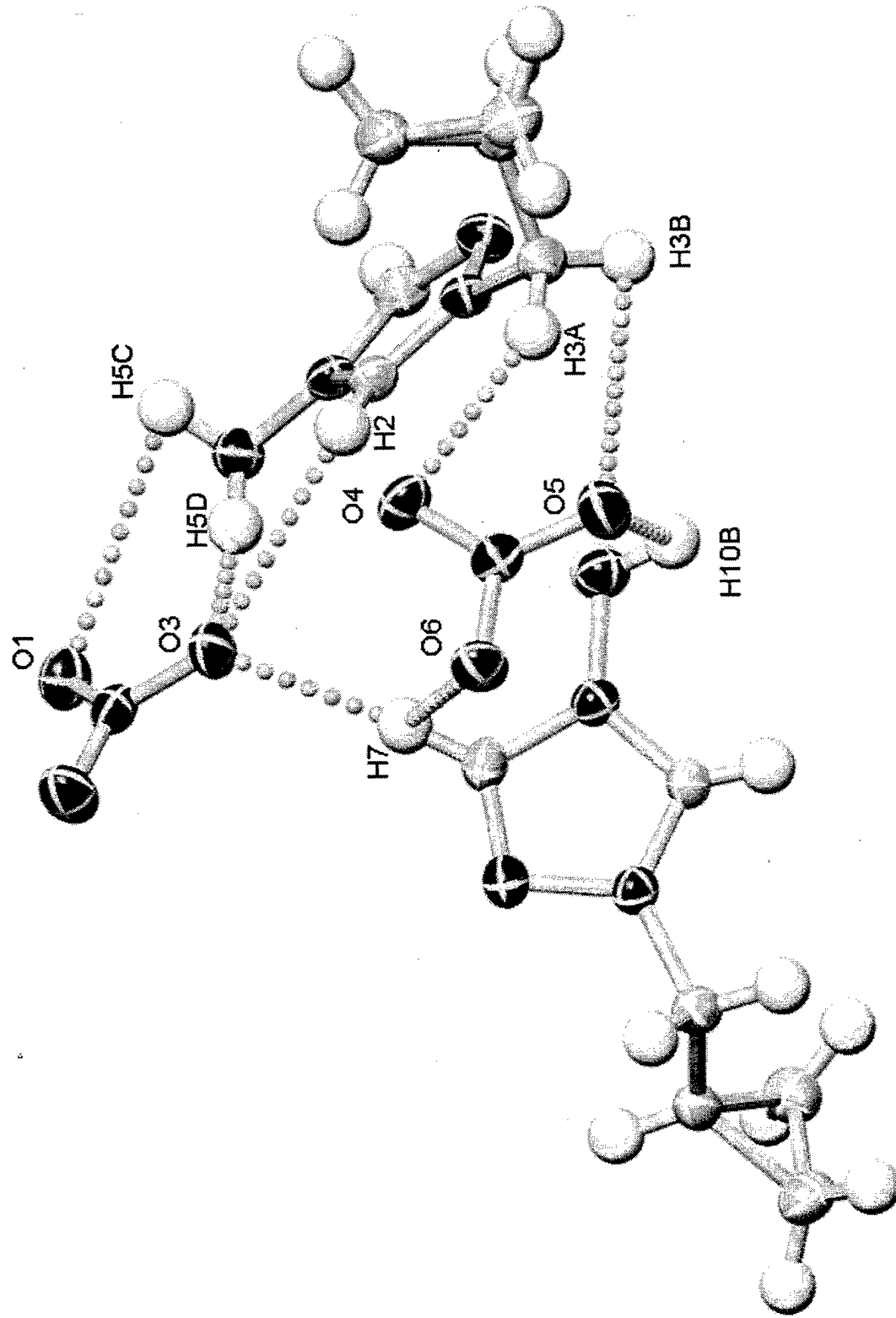
Run Date: 16-Jan-02 23:04



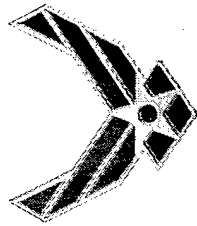
DSC of 1-n-propyl-4-amino-1,2,4-triazolium nitrate



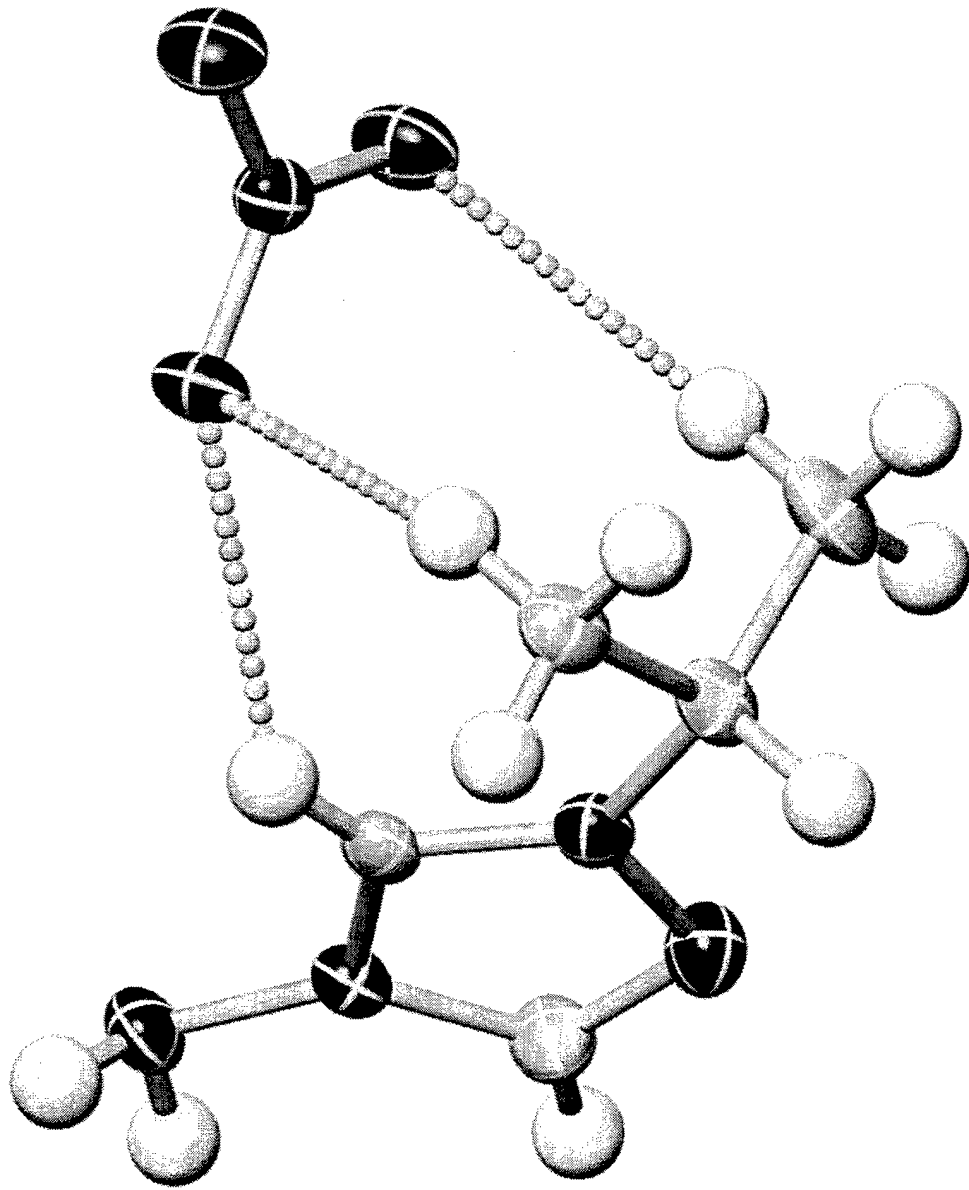
Ionic Liquids



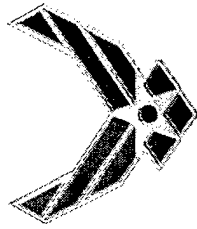
Single crystal x-ray diffraction study of 1-methylcyclopropyl-4-amino-1,2,4-triazolium nitrate.



Ionic Liquids



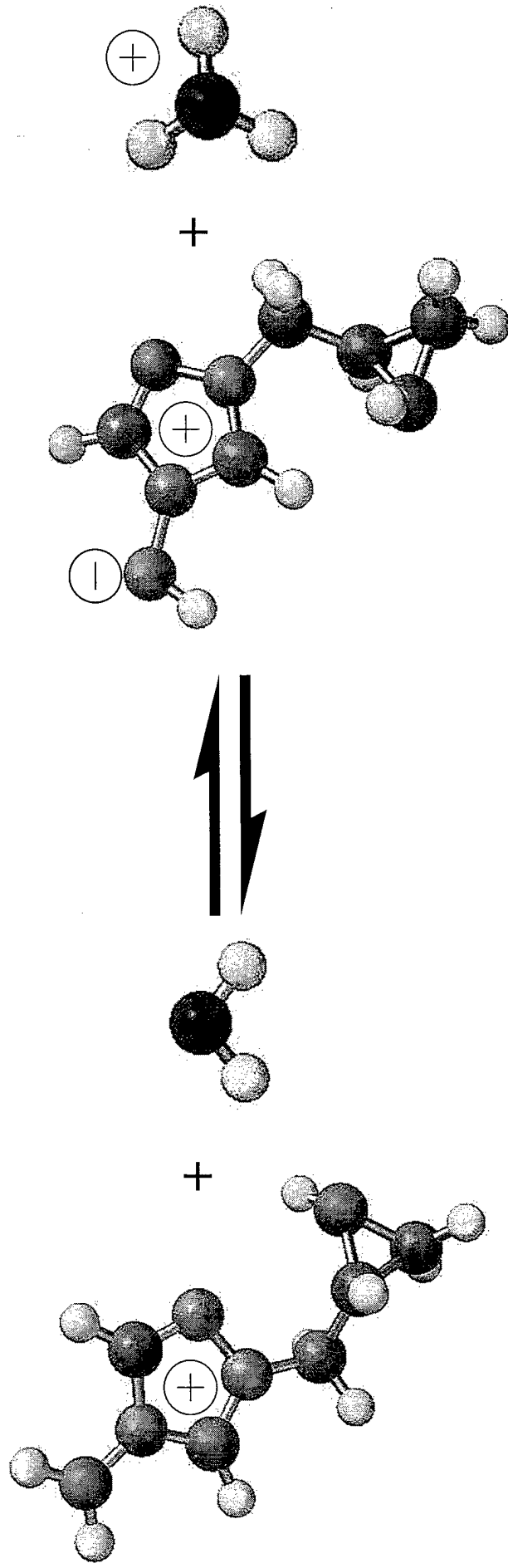
Single crystal x-ray diffraction structure of 1-isopropyl-4-amino-1,2,4-triazolium nitrate

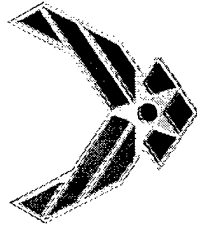


Ionic Liquids



The new energetic cations are weakly acidic in nature, aqueous solutions have a pH of around 4 which suggests the equilibrium involving a zwitterionic 1-alkyl-4-amido-1,2,4-triazolium species. This equilibrium could be one possible way for the ionic liquids to “come apart”.





Ionic Liquids



Summary and Conclusions

Oxyamines and nitrocyuanamide ions make for low melting and energetic salts, however both are plagued by poor thermal behavior and impact/friction sensitivity.

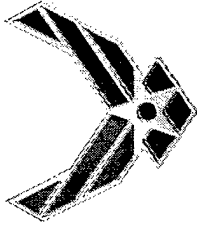
A large new class of low melting salts which should be considered as new members of the well known class of materials referred to as ionic liquids has been synthesized and well characterized.

Using asymmetric cation shapes and poor cation-anion fit, an analogue system to the well known 1,3-dialkylsubstituted imidazolium cation family, based upon 1-substituted-4-amino-1,2,4-triazolium cations paired with the bromide and nitrate ions has been explored.

Facile synthesis routes from commercially available materials coupled with high yield and purity reactions make these new materials very exciting.

Several single crystal x-ray diffraction studies of several structures have been carried out proving the expected structure as well as revealing extensive hydrogen bonding in the solid state.

Physical properties of 1-substituted-4-amino-1,2,4-triazolium salts included much higher viscosities, higher densities, and much more polar behavior than that of imidazolium ionic liquids.



Ionic Liquids



ACKNOWLEDGEMENTS

- MIKE BERMAN (AFOSR)
- WAYNE KALLIOMAA; RONALD CHANNELL(AFRL/PRSP)
- JOHN WILKES (USAF)
- JEFF SHEEHY(NASA/MARSHALL AND UA/HUNTSVILLE)
- CLAUDE MERRILL
- TOMMY HIGHSMITH
- JEFF BOTTARO, MARK PETRIE (SRI, INT.)
- MIKE HUGGINS (AFRL SUPPORT)